



US012296595B2

(12) **United States Patent**  
**Hasegawa et al.**

(10) **Patent No.:** **US 12,296,595 B2**

(45) **Date of Patent:** **May 13, 2025**

(54) **LIQUID EJECTING APPARATUS AND LIQUID FILLING METHOD**

2/14233; B41J 2/14; B41J 2002/14419; B41J 2202/20; B41J 2202/11; B41J 2202/19; B41J 2002/14338; B41J 2202/12

See application file for complete search history.

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(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 167 days.

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(21) Appl. No.: **18/328,131**

(22) Filed: **Jun. 2, 2023**

(57) **ABSTRACT**

A liquid ejecting apparatus includes a liquid ejection head, a supply tank, a recovery tank, a supply flow path, a recovery flow path, a pressurizing mechanism pressurizing the inside of the supply tank, and a depressurizing mechanism depressurizing the inside of the recovery tank. A filling period, in which a filling process is performed to fill, with the liquid, a nozzle, the supply flow path, and the recovery flow path, includes a period that is after a meniscus is formed in the nozzle and before the liquid reaches the recovery flow path. In the period, the pressurizing and the depressurizing mechanisms are driven; and in the period,  $P_{t\_out} > -|P_m|$  is satisfied, where  $P_m$  indicates a pressure at which the meniscus is broken and  $P_{t\_out}$  indicates a pressure in the recovery tank.

(65) **Prior Publication Data**

US 2023/0391092 A1 Dec. 7, 2023

**20 Claims, 13 Drawing Sheets**

(30) **Foreign Application Priority Data**

Jun. 3, 2022 (JP) ..... 2022-090712

(51) **Int. Cl.**

**B41J 2/175** (2006.01)

(52) **U.S. Cl.**

CPC ..... **B41J 2/175** (2013.01)

(58) **Field of Classification Search**

CPC . B41J 2/18; B41J 2/175; B41J 2/17596; B41J

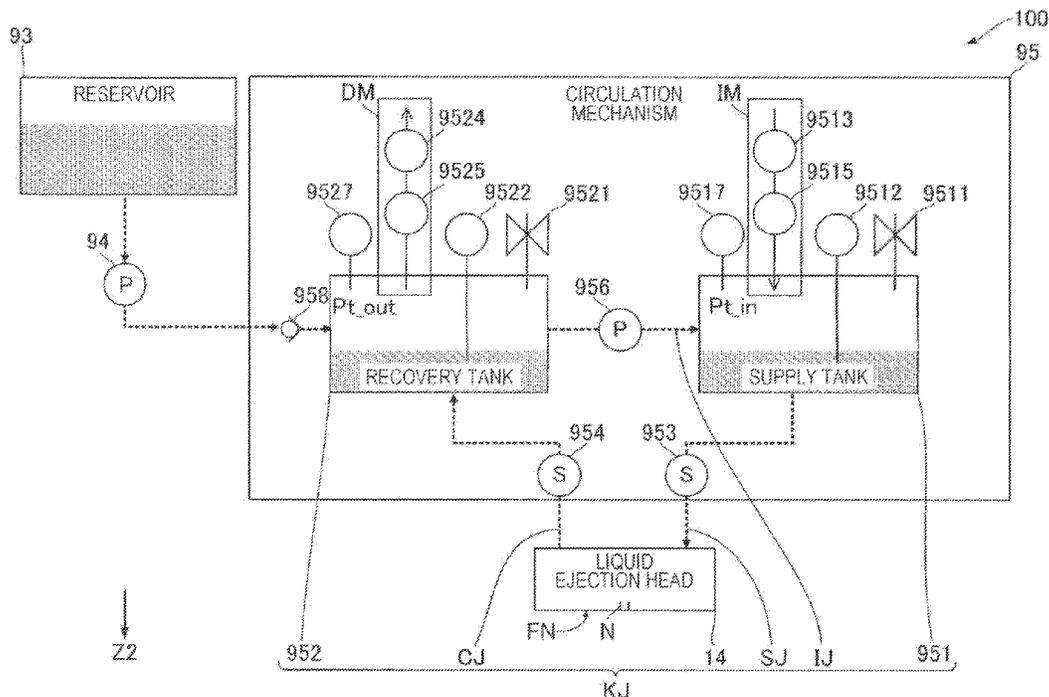
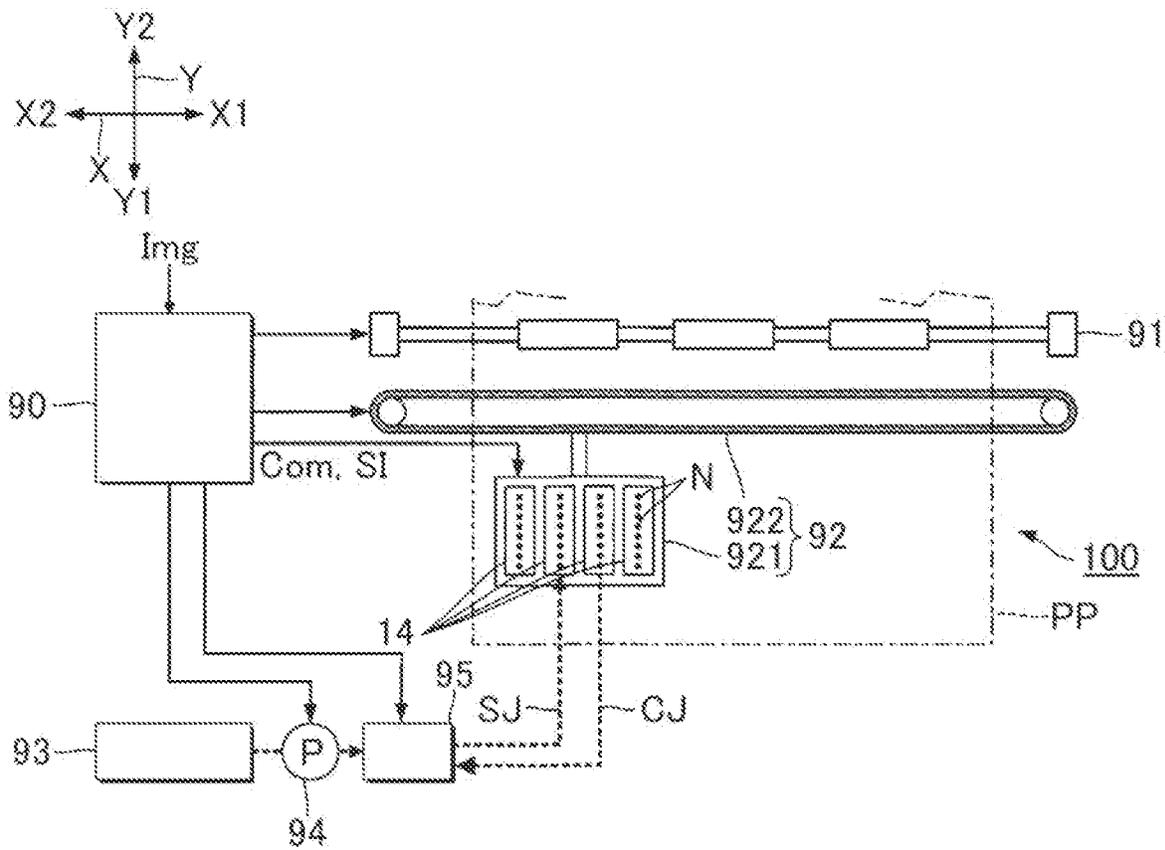


FIG. 1



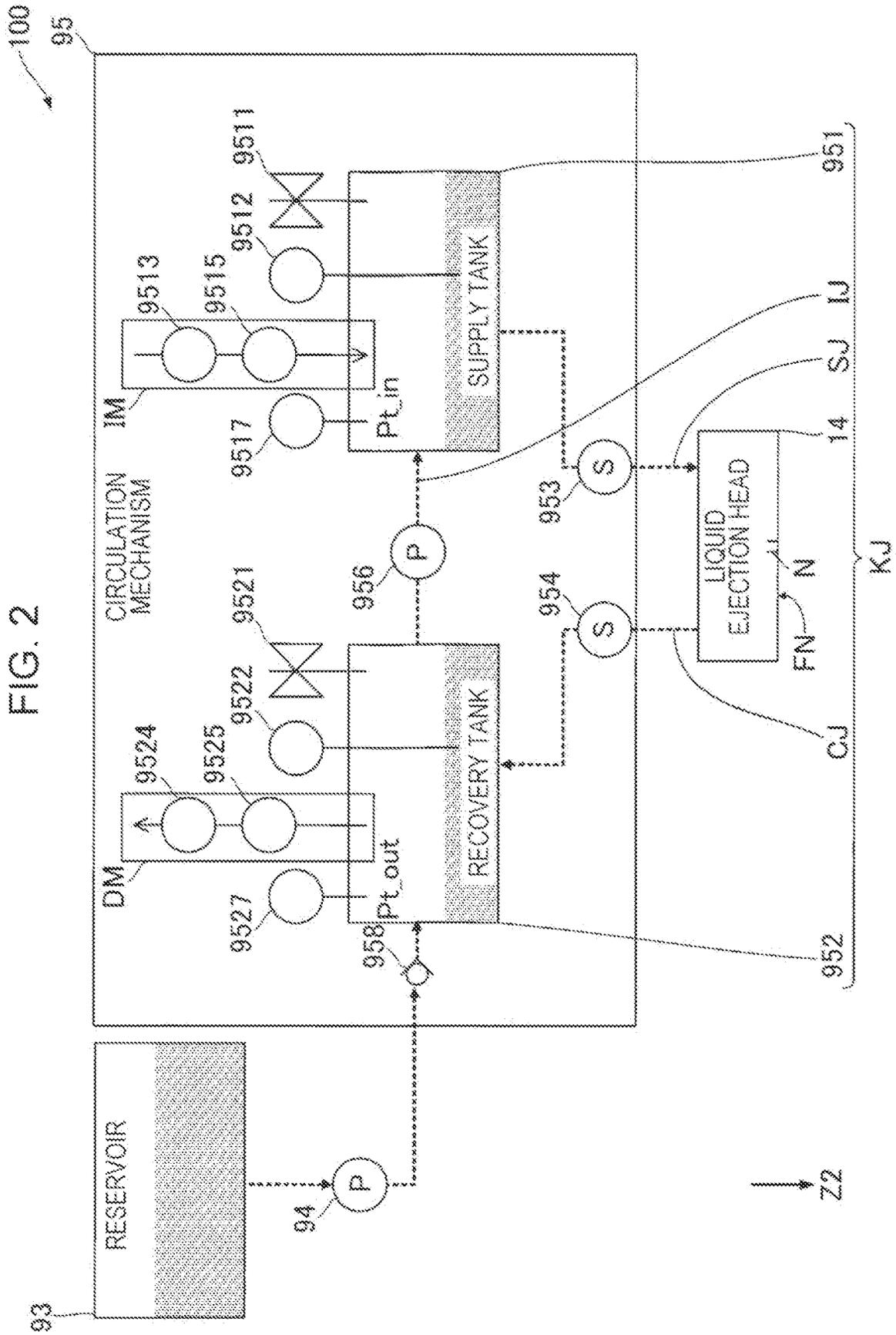


FIG. 3

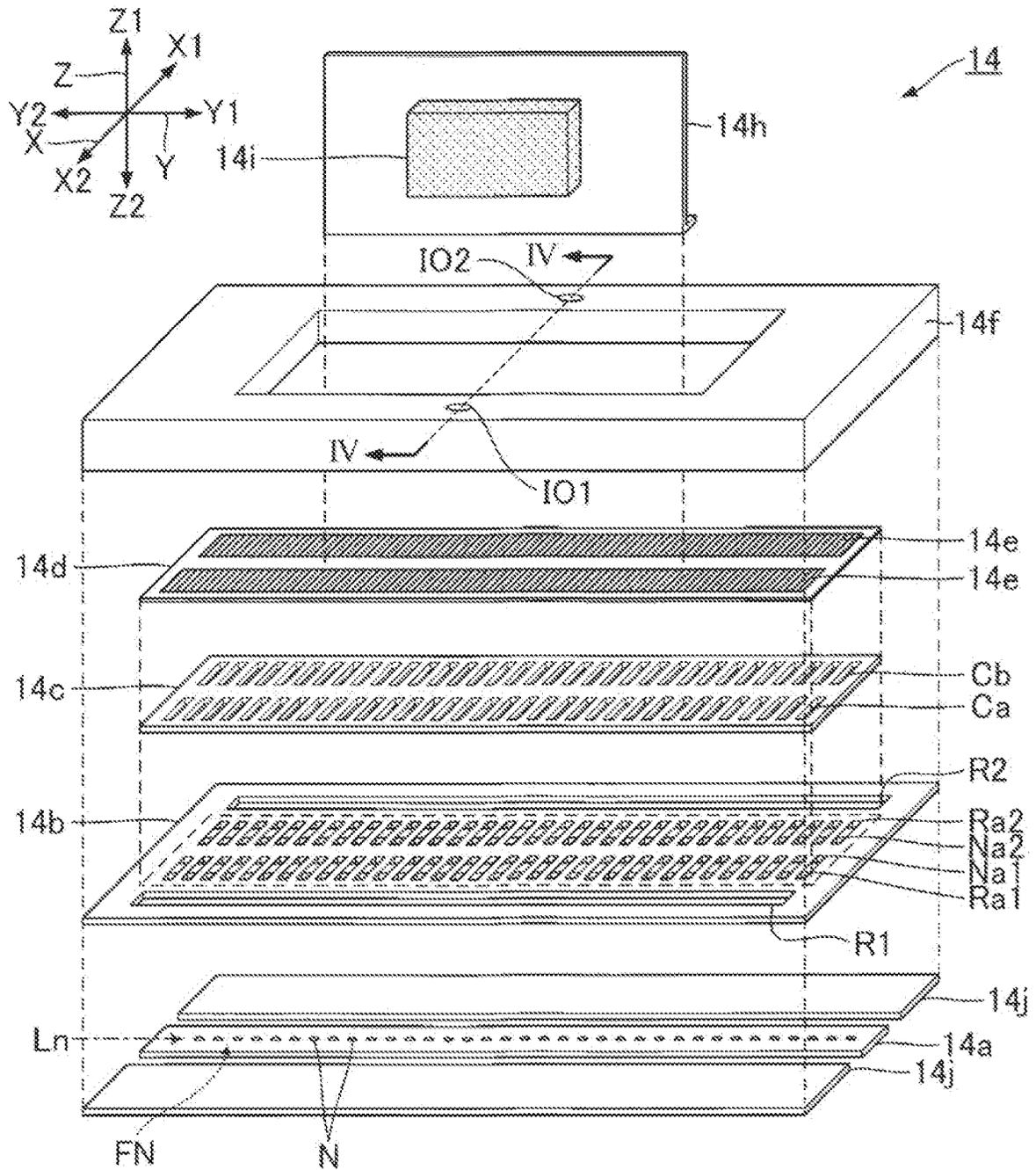


FIG. 4

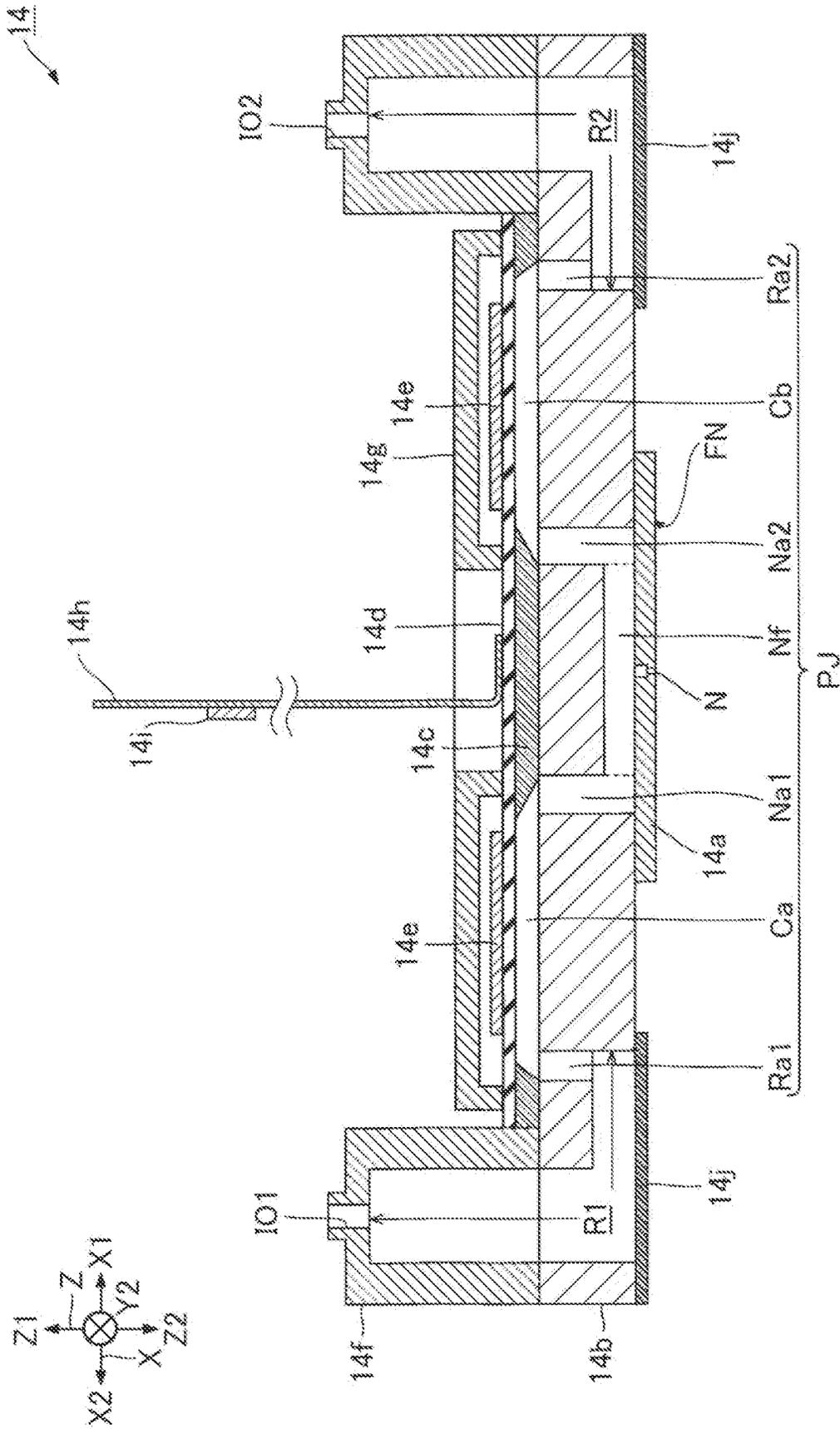
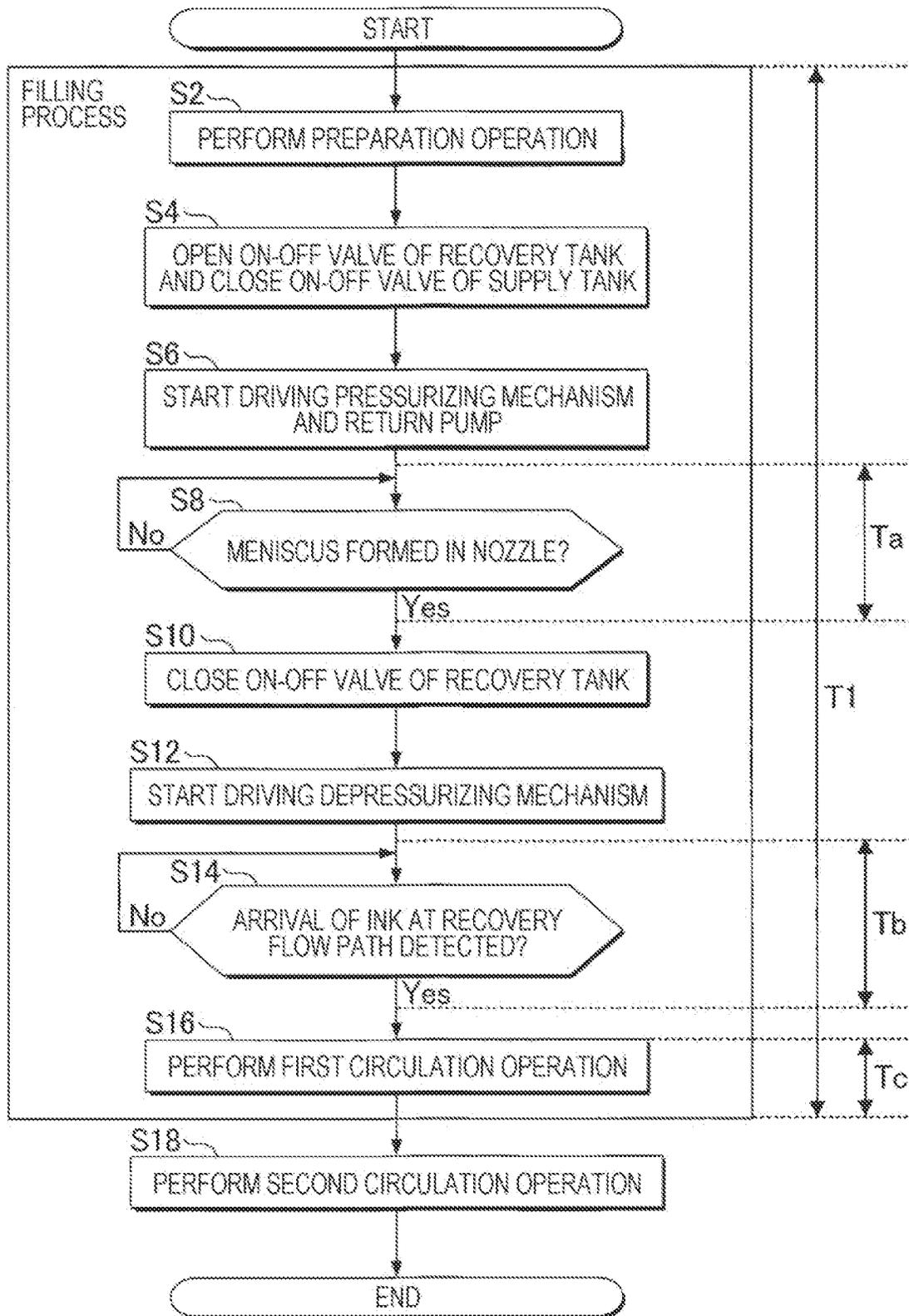


FIG. 5



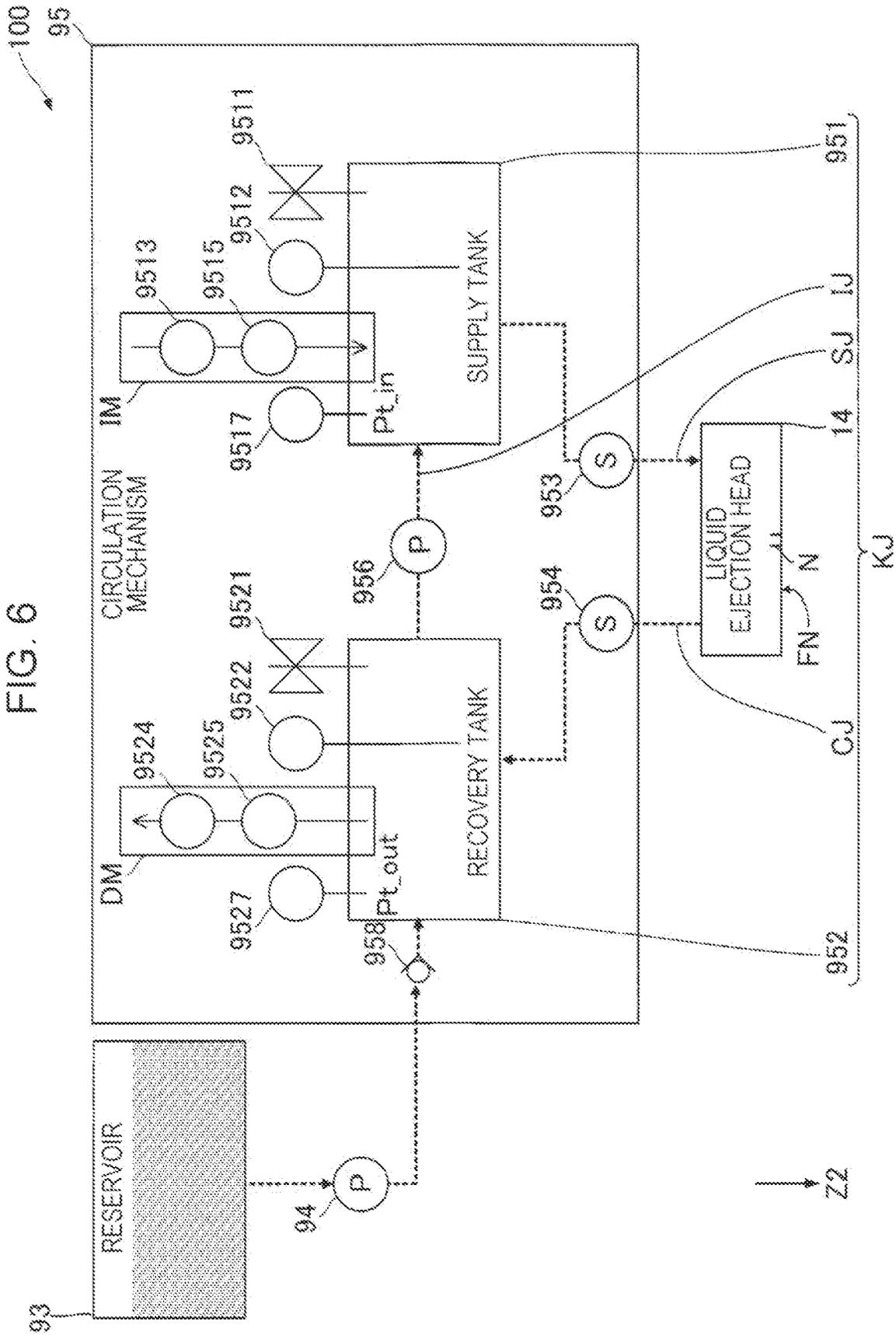


FIG. 7

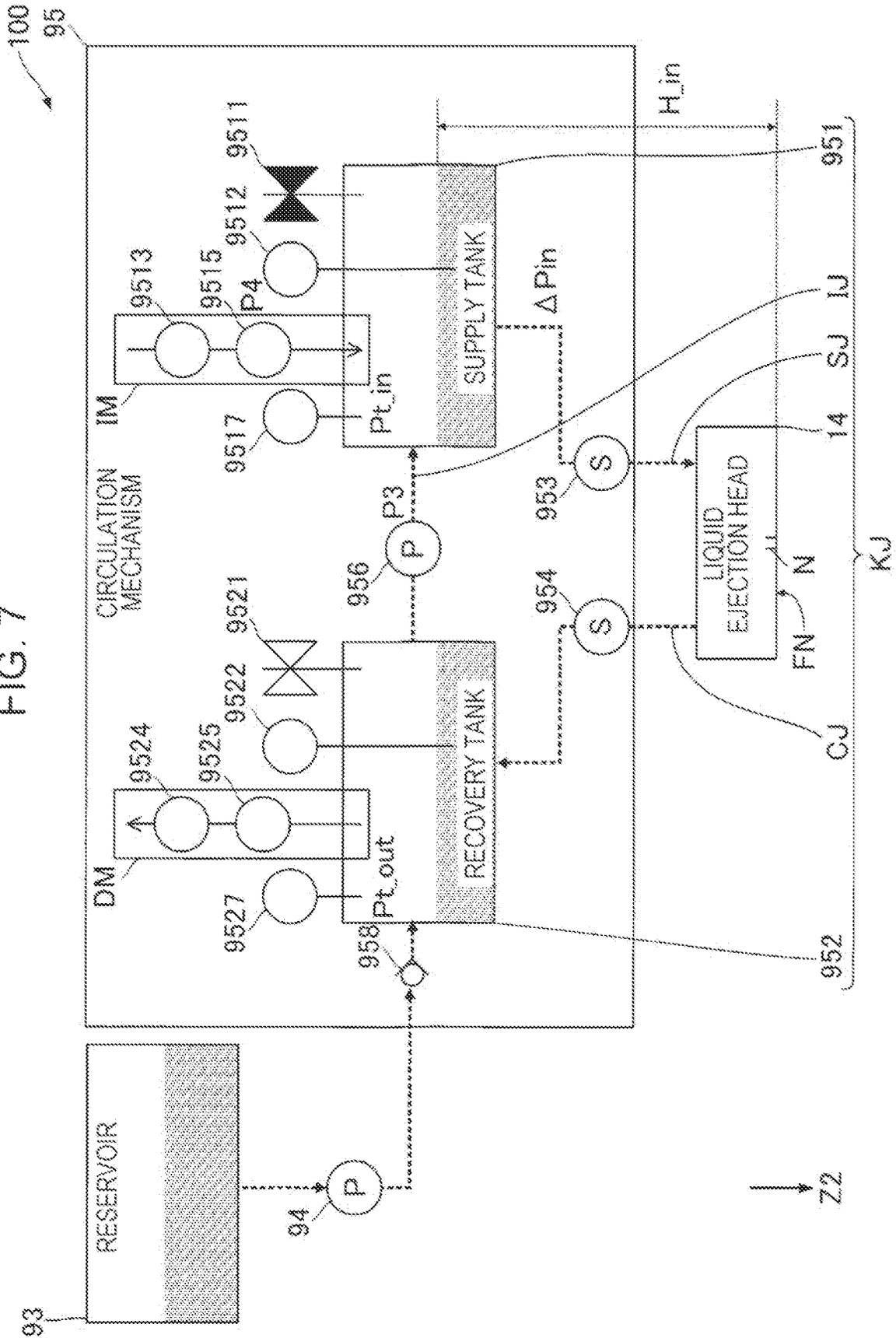




FIG. 9

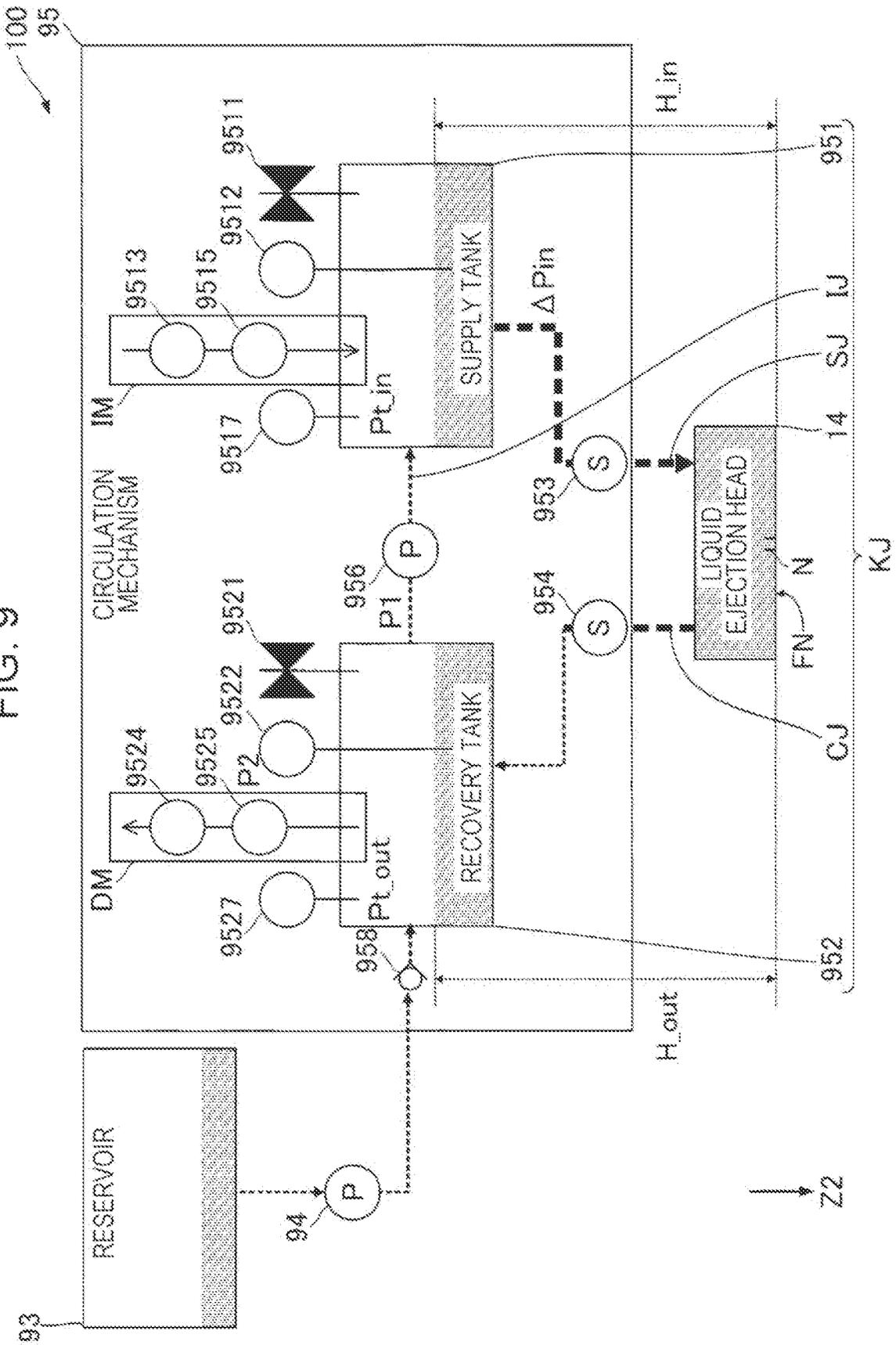


FIG. 10

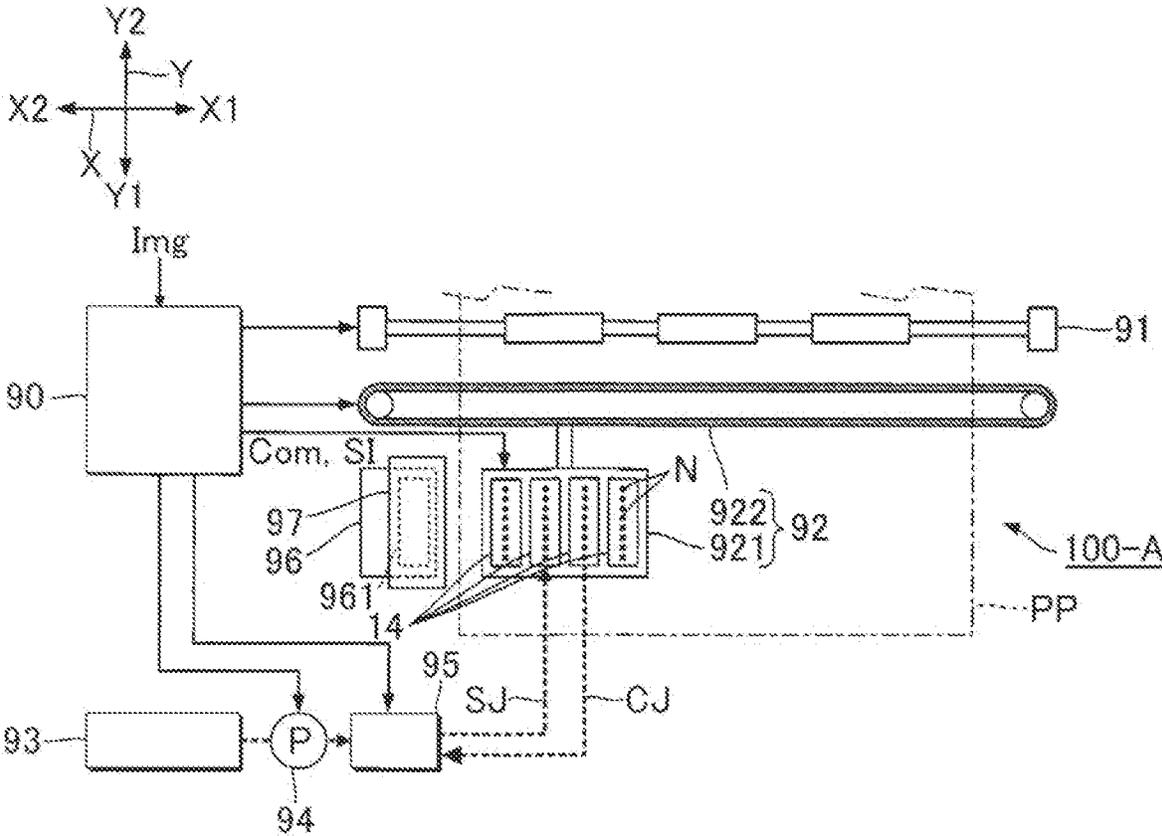


FIG. 11

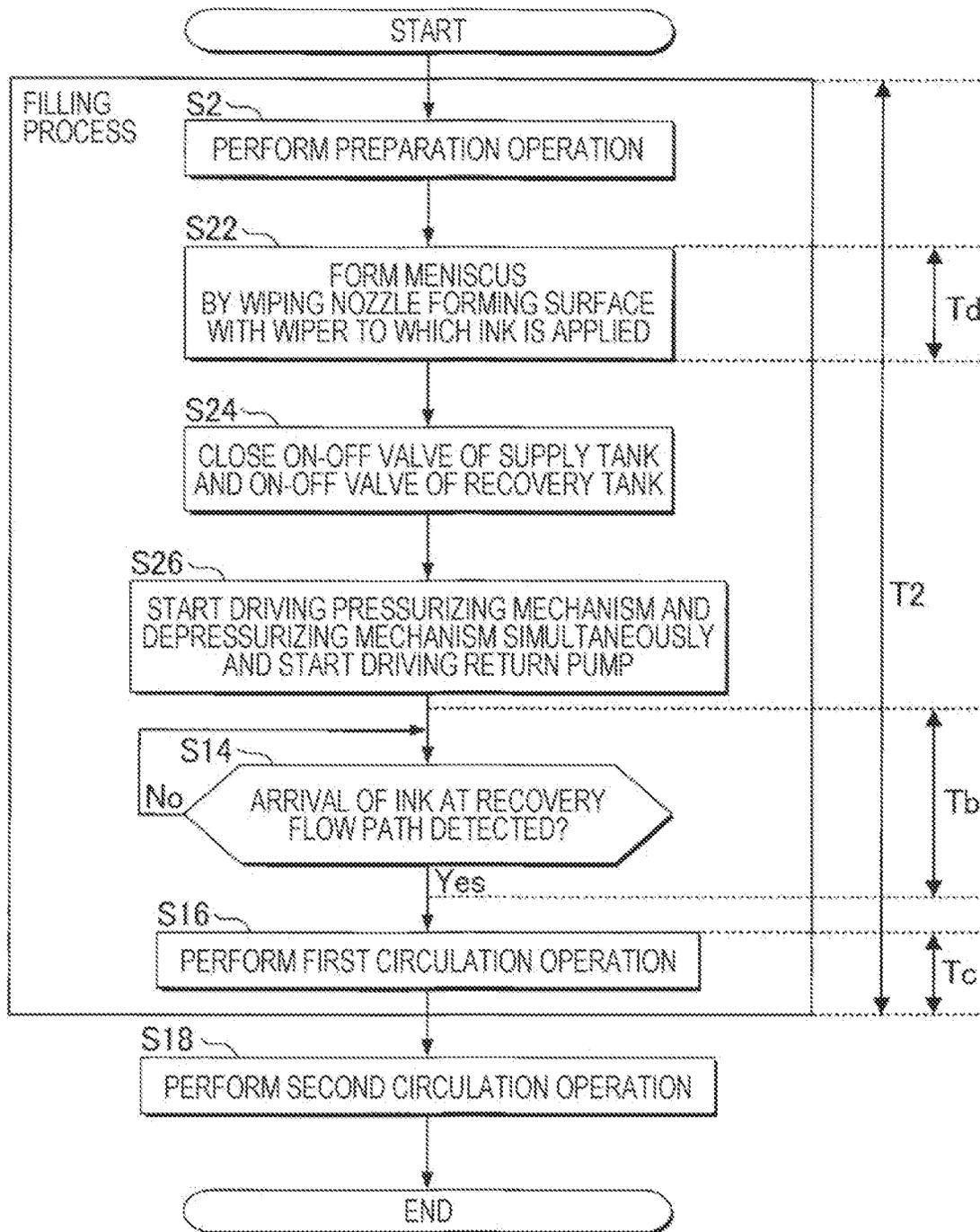
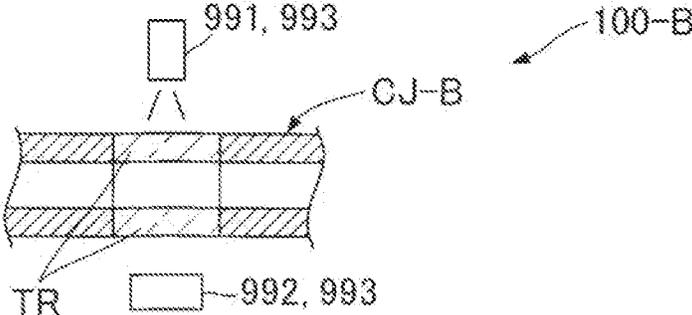




FIG. 13



## LIQUID EJECTING APPARATUS AND LIQUID FILLING METHOD

The present application is based on, and claims priority from JP Application Serial Number 2022-090712, filed Jun. 3, 2022 the disclosure of which is hereby incorporated by reference herein in its entirety.

### BACKGROUND

#### 1. Technical Field

The present disclosure relates to a liquid ejecting apparatus and a liquid filling method.

#### 2. Related Art

There is a known liquid ejecting apparatus, such as an ink jet printer, that includes a liquid ejection head including a nozzle for ejecting a liquid, such as ink. For example, JP-A-2015-058581 describes a liquid ejecting apparatus including a supply tank that temporarily stores a liquid to be supplied to a liquid ejection head, a recovery tank that temporarily stores the liquid recovered from the liquid ejection head, a supply flow path for supplying the liquid from the supply tank to the liquid ejection head, and a recovery flow path for recovering the liquid from the liquid ejection head to the recovery tank. In this liquid ejecting apparatus, when filling the nozzle, the supply flow path, and the recovery flow path with the liquid, the liquid is discharged from the nozzle by pressurizing the insides of both of the supply tank and the recovery tank.

In the related-art technology described above, to reduce the amount of liquid to be discharged from the nozzle when filling the nozzle, the supply flow path, and the recovery flow path with the liquid, a filling process may be performed such that the nozzle, the supply flow path, and the recovery flow path are filled with the liquid by pressurizing the inside of the supply tank and depressurizing the inside of the recovery tank instead of pressurizing the insides of both of the supply tank and the recovery tank. However, when the inside of the recovery tank is depressurized during the filling process, air bubbles may be drawn into the flow path in the liquid ejection head.

### SUMMARY

According to an aspect of the present disclosure, a liquid ejecting apparatus includes a liquid ejection head including a nozzle that ejects a liquid, a supply tank that temporarily stores the liquid to be supplied to the liquid ejection head, a recovery tank that temporarily stores the liquid recovered from the liquid ejection head, a supply flow path through which the liquid is supplied from the supply tank to the liquid ejection head, a recovery flow path through which the liquid is recovered from the liquid ejection head to the recovery tank, a pressurizing mechanism that pressurizes the inside of the supply tank, and a depressurizing mechanism that depressurizes the inside of the recovery tank. A filling period, in which a filling process is performed to fill, with the liquid, the nozzle, the supply flow path, and the recovery flow path that are not filled with the liquid, includes a first period that is after a meniscus of the liquid is formed in the nozzle and before the liquid reaches the recovery flow path. In the first period, the pressurizing mechanism and the depressurizing mechanism are driven; and in the first period,  $P_{t\_out} > -|P_m|$  is satisfied, where  $P_m$  indicates a pressure at

which the meniscus of the liquid formed in the nozzle is broken and  $P_{t\_out}$  indicates a pressure in the recovery tank.

According to an aspect of the present disclosure, a liquid filling method is performed by a liquid ejecting apparatus including a liquid ejection head including a nozzle that ejects a liquid, a supply tank that temporarily stores the liquid to be supplied to the liquid ejection head, a recovery tank that temporarily stores the liquid recovered from the liquid ejection head, a supply flow path through which the liquid is supplied from the supply tank to the liquid ejection head, a recovery flow path through which the liquid is recovered from the liquid ejection head to the recovery tank, a pressurizing mechanism that pressurizes the inside of the supply tank, and a depressurizing mechanism that depressurizes the inside of the recovery tank. The liquid filling method includes when a filling period, in which a filling process is performed to fill, with the liquid, the nozzle, the supply flow path, and the recovery flow path that are not filled with the liquid, includes a first period that is after a meniscus of the liquid is formed in the nozzle and before the liquid reaches the recovery flow path, driving the depressurizing mechanism such that  $P_{t\_out} > -|P_m|$  is satisfied in the first period, where  $P_m$  indicates a pressure at which the meniscus of the liquid formed in the nozzle is broken and  $P_{t\_out}$  indicates a pressure in the recovery tank.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a drawing illustrating an example of a liquid ejecting apparatus according to a first embodiment.

FIG. 2 is a drawing illustrating a circulation mechanism.

FIG. 3 is an exploded perspective view of a liquid ejection head.

FIG. 4 is a cross-sectional view taken along line IV-IV of FIG. 3.

FIG. 5 is a flowchart illustrating a process performed by a controller to fill flow paths with ink.

FIG. 6 is a drawing for describing a preparation operation.

FIG. 7 is a drawing illustrating a state of the liquid ejecting apparatus in a period  $T_a$ .

FIG. 8 is a drawing illustrating a state of the liquid ejecting apparatus in a period  $T_b$ .

FIG. 9 is a drawing illustrating a state of the liquid ejecting apparatus in a period  $T_c$ .

FIG. 10 is a drawing illustrating an example of a liquid ejecting apparatus according to a second embodiment.

FIG. 11 is a flowchart illustrating a process performed by a controller to fill flow paths with ink according to the second embodiment.

FIG. 12 is a drawing illustrating a state of the liquid ejecting apparatus of the second embodiment immediately after the end of a period  $T_d$ .

FIG. 13 is a drawing for describing a liquid ejecting apparatus according to a first variation.

### DESCRIPTION OF EXEMPLARY EMBODIMENTS

Embodiments of the present disclosure are described below with reference to the drawings. In the drawings, the sizes and scales of components may be different from the actual sizes and scales of the components. The embodiments described below are specific examples of the present disclosure and include various limitations. However, the scope of the present disclosure is not limited to those embodiments unless otherwise mentioned.

## 1. First Embodiment

A liquid ejecting apparatus **100** according to a first embodiment is described below with reference to FIG. 1.

## 1-1. Outline of Liquid Ejecting Apparatus

FIG. 1 is a drawing illustrating an example of the liquid ejecting apparatus **100** according to the first embodiment. The liquid ejecting apparatus **100** according to the first embodiment is an ink jet printing device that ejects ink onto a medium PP. The medium PP is typically printing paper but may also be any other type of printing medium such as a resin film or a fabric. Here, ink is an example of a “liquid”.

As illustrated in FIG. 1, the liquid ejecting apparatus **100** includes a reservoir **93** that stores ink. The reservoir **93** may be implemented by, for example, a cartridge attachable to and detachable from the liquid ejecting apparatus **100**, a bag-shaped ink pack formed of a flexible film, or an ink tank that can be refilled with ink. The reservoir **93** may store multiple types of ink with different colors.

As illustrated in FIG. 1, the liquid ejecting apparatus **100** includes multiple liquid ejection heads **14**, a controller **90**, a conveying mechanism **91**, a moving mechanism **92**, the reservoir **93**, a pump **94**, a circulation mechanism **95**, a supply flow path SJ, and a recovery flow path CJ. Alternatively, the liquid ejecting apparatus **100** may include only one liquid ejection head **14**.

The controller **90** includes a processing circuit, such as a CPU or an FPGA, and a memory circuit, such as a semiconductor memory; and controls components of the liquid ejecting apparatus **100**. Here, CPU stands for central processing unit. FPGA stands for field programmable gate array. The controller **90** may include multiple processing circuits.

The conveying mechanism **91** conveys the medium PP in a Y1 direction under the control of the controller **90**. In the descriptions below, the Y1 direction and a Y2 direction, which is the opposite of the Y1 direction, are collectively referred to as a Y-axis direction.

The moving mechanism **92**, under the control of the controller **90**, moves the multiple liquid ejection heads **14** back and forth in an X1 direction and an X2 direction that is the opposite of the X1 direction. In the descriptions below, the X1 direction and the X2 direction may be collectively referred to as an X-axis direction. Here, the X1 direction intersects the Y1 direction. Typically, the X1 direction is orthogonal to the Y1 direction. The moving mechanism **92** includes a housing case **921** that houses the multiple liquid ejection heads **14** and an endless belt **922** to which the housing case **921** is attached. The reservoir **93** may also be housed in the housing case **921** together with the multiple liquid ejection heads **14**.

The pump **94** supplies ink stored in the reservoir **93** to the circulation mechanism **95** under the control of the controller **90**. The pump **94** is, for example, a tube pump. However, the pump **94** is not limited to a tube pump and may be a diaphragm pump or a syringe pump.

The circulation mechanism **95**, under the control of the controller **90**, supplies the ink, which is supplied from the reservoir **93** via the pump **94**, to the liquid ejection heads **14** via the supply flow path SJ. Also, under the control of the controller **90**, the circulation mechanism **95** recovers the ink from the liquid ejection heads **14** via the recovery flow path CJ and causes the recovered ink to flow back to the liquid ejection heads **14**. Each of the supply flow path SJ and the recovery flow path CJ is formed of, for example, a flexible

tube. The circulation mechanism **95** may instead be controlled by a device other than the controller **90**.

The controller **90** receives image data *Img* indicating an image from a host computer such as a personal computer or a digital camera. Based on the received image data *Img*, the controller **90** supplies, to each liquid ejection head **14**, a drive signal *Com* for driving the liquid ejection head **14** and a control signal *SI* for controlling the liquid ejection head **14**. Then, the liquid ejection head **14** is driven by the drive signal *Com* under the control of the control signal *SI* and ejects ink in a Z2 direction from some or all of nozzles *N* provided in the liquid ejection head **14**. The Z2 direction is orthogonal to the X1 direction and the Y1 direction. In the descriptions below, the Z2 direction and a Z1 direction, which is the opposite of the Z2 direction, may be collectively referred to as a Z-axis direction. In the present embodiment, the Z2 direction is the gravity direction (vertical direction). The nozzles *N* are described later with reference to FIGS. 3 and 4.

The liquid ejection head **14** performs a print operation in which ink is ejected from some or all of the multiple nozzles *N* in synchronization with the conveyance of the medium PP by the conveying mechanism **91** and the back-and-forth movement of the liquid ejection head **14** by the moving mechanism **92** so that the ejected ink lands on the surface of the medium PP and thereby forms a desired image on the surface of the medium PP.

FIG. 2 is a drawing illustrating the circulation mechanism **95**. As illustrated in FIG. 2, the circulation mechanism **95** includes a supply tank **951**, a recovery tank **952**, a pressure sensor **953**, a pressure sensor **954**, a return pump **956**, and a check valve **958**. In each of FIG. 2 and FIGS. 7, 8, 9, and 12 described later, to facilitate the understanding, the amount of ink stored in each of the supply tank **951**, the recovery tank **952**, and the reservoir **93** is schematically indicated by a shaded area. Also, in FIGS. 2, 7, 8, 9, and 12, the nozzle *N* is illustrated in the liquid ejection head **14** to make it easier to discern whether a meniscus of ink is formed in the nozzle *N*. Also, a nozzle forming surface *FN*, in which the nozzle *N* is formed, is illustrated in each of FIGS. 2, 7, 8, 9, and 12. The nozzle forming surface *FN* is described later with reference to FIGS. 3 and 4.

Each of the supply tank **951** and the recovery tank **952** temporarily stores ink. The supply tank **951** temporarily stores ink to be supplied to each of the multiple liquid ejection heads **14**. The supply tank **951** supplies ink to each of the multiple liquid ejection heads **14** via the supply flow path SJ. The recovery tank **952** temporarily stores ink recovered from each of the multiple liquid ejection heads **14**. The recovery tank **952** also temporarily stores ink supplied from the reservoir **93**. The recovery tank **952** recovers ink from each of the multiple liquid ejection heads **14** via the recovery flow path CJ.

The supply tank **951** is provided with an on-off valve **9511**, a liquid level sensor **9512**, a pressurizing mechanism *IM* that pressurizes the inside of the supply tank **951**, and a pressure sensor **9517**. The recovery tank **952** is provided with an on-off valve **9521**, a liquid level sensor **9522**, a depressurizing mechanism *DM* that depressurizes the inside of the recovery tank **952**, and a pressure sensor **9527**.

The on-off valve **9511**, under the control of the controller **90**, can close the supply tank **951** and open the supply tank **951** so that the supply tank **951** communicates with the atmosphere. The on-off valve **9521**, under the control of the controller **90**, can close the recovery tank **952** and open the recovery tank **952** so that the recovery tank **952** communicates with the atmosphere. Each of the on-off valve **9511** and

the on-off valve **9521** may be implemented by any type of valve, such as a diaphragm valve, a solenoid valve, or a motorized valve, that can be controlled by a device, such as the controller **90**. In the descriptions below, closing the supply tank **951** with the on-off valve **9511** may be expressed as “close the on-off valve **9511**”, and opening the supply tank **951** with the on-off valve **9511** may be expressed as “open the on-off valve **9511**”. Similarly, closing the recovery tank **952** with the on-off valve **9521** may be expressed as “close the on-off valve **9521**”, and opening the recovery tank **952** with the on-off valve **9521** may be expressed as “open the on-off valve **9521**”.

The liquid level sensor **9512** detects whether the level of ink in the supply tank **951** is greater than or equal to a predetermined height. The liquid level sensor **9522** detects whether the level of ink in the recovery tank **952** is greater than or equal to a predetermined height. Each of the liquid level sensor **9512** and the liquid level sensor **9522** outputs information indicating the detection result to the controller **90**.

The pressurizing mechanism **IM** includes a compressor **9513** and a regulator **9515**. The depressurizing mechanism **DM** includes a vacuum pump **9524** and a regulator **9525**.

The compressor **9513** and the vacuum pump **9524** cause a difference between the pressure in the supply tank **951** and the pressure in the recovery tank **952**. Specifically, the compressor **9513** generates a positive pressure higher than the atmospheric pressure. The vacuum pump **9524** generates a negative pressure lower than the atmospheric pressure. Here, the pressurizing mechanism **IM** may include a pump, such as a tube pump, a syringe pump, or a diaphragm pump, in place of the compressor **9513**.

The regulator **9515** is disposed between the compressor **9513** and the supply tank **951**. The regulator **9515**, under the control of the controller **90**, adjusts the pressure generated by the compressor **9513** and supplies the adjusted pressure to the supply tank **951**. In the descriptions below, the pressure in the supply tank **951** may be indicated by  $P_{t\_in}$ .

The regulator **9525** is disposed between the vacuum pump **9524** and the recovery tank **952**. The regulator **9525**, under the control of the controller **90**, adjusts the pressure generated by the vacuum pump **9524** and supplies the adjusted pressure to the recovery tank **952**. In the descriptions below, the pressure in the recovery tank **952** may be indicated by  $P_{t\_out}$ .

The pressure sensor **9517** measures the pressure  $P_{t\_in}$  in the supply tank **951**. The pressure sensor **9527** measures the pressure  $P_{t\_out}$  in the recovery tank **952**. Each of the pressure sensor **9517** and the pressure sensor **9527** sends measurement information indicating the measured pressure to the controller **90**.

The return pump **956** is disposed in a relay flow path **IJ** through which the supply tank **951** communicates with the recovery tank **952**. The return pump **956** is, for example, a tube pump. The return pump **956**, under the control of the controller **90**, sends ink in the recovery tank **952** to the supply tank **951** via the relay flow path **IJ**.

The pressure sensor **953** measures the pressure in the supply flow path **SJ**. The pressure sensor **954** measures the pressure in the recovery flow path **CJ**. Each of the pressure sensor **953** and the pressure sensor **954** sends measurement information indicating the measured pressure to the controller **90**. The pressure sensor **954** is an example of a “detector”.

The check valve **958** prevents the backflow of ink supplied from the reservoir **93** to the recovery tank **952**.

As described above, under the control of the controller **90**, the liquid ejecting apparatus **100** performs a circulation operation in which the pressure  $P_{t\_in}$  in the supply tank **951** is made higher than the pressure  $P_{t\_out}$  in the recovery tank **952** to cause the ink to circulate through a circulation path **KJ** including the liquid ejection head **14**, the supply tank **951**, the supply flow path **SJ**, the recovery tank **952**, the recovery flow path **CJ**, and the relay flow path **IJ**. When the circulation operation is performed, the ink flows from the supply tank **951** via the supply flow path **SJ** into the liquid ejection head **14**, the ink is recovered from the liquid ejection head **14** via the recovery flow path **CJ** to the recovery tank **952**, and the ink is caused by the return pump **956** to flow from the recovery tank **952** via the relay flow path **IJ** to the supply tank **951**. Thus, the ink is circulated. The circulation operation is divided into a first circulation operation and a second circulation operation. The flow rate in the first circulation operation is greater than the flow rate in the second circulation operation.

## 1-2. Outline of Liquid Ejection Head

FIG. **3** is an exploded perspective view of the liquid ejection head **14**. FIG. **4** is a cross-sectional view taken along line **IV-IV** of FIG. **3**. Line **IV-IV** is a virtual line segment that is parallel to the **X**-axis and passes through a nozzle flow path **Nf**.

As illustrated in FIGS. **3** and **4**, the liquid ejection head **14** includes a nozzle substrate **14a**, a flow path substrate **14b**, a pressure chamber substrate **14c**, a vibration plate **14d**, multiple piezoelectric elements **14e**, a case **14f**, a protective plate **14g**, a wiring substrate **14h**, and vibration absorbers **14j**.

As illustrated in FIGS. **3** and **4**, the nozzle substrate **14a**, the flow path substrate **14b**, the pressure chamber substrate **14c**, and the vibration plate **14d** are stacked in this order in the **Z1** direction. Each of these components extends along the **Y**-axis and is manufactured by, for example, processing a single-crystal substrate of silicon using a semiconductor processing technology. Also, these components are joined to each other with, for example, an adhesive. Another layer, such as an adhesive layer, or a substrate may be interposed between any two adjacent components among these components as necessary.

Multiple nozzles **N** are formed in the nozzle substrate **14a**. Each of the multiple nozzles **N** is a through hole that passes through the nozzle substrate **14a** and through which ink passes. The multiple nozzles **N** are arranged in the **Y**-axis direction. The multiple nozzles **N** form a nozzle array **Ln** that is parallel to the **Y**-axis. The nozzle substrate **14a** has the nozzle forming surface **FN** in which the multiple nozzles **N** are formed. The nozzle forming surface **FN** is one of the two surfaces of the nozzle substrate **14a** and faces the **Z2** direction.

In the flow path substrate **14b**, parts of a first common liquid chamber **R1** and a second common liquid chamber **R2** and parts of individual flow paths **PJ** excluding pressure chambers **Ca** and pressure chambers **Cb** are formed. That is, in the flow path substrate **14b**, nozzle flow paths **Nf**, first communication flow paths **Na1**, second communication flow paths **Na2**, individual supply flow paths **Ra1**, and individual discharge flow paths **Ra2** are formed.

Parts of the first common liquid chamber **R1** and the second common liquid chamber **R2** are spaces that pass through the flow path substrate **14b**. The vibration absorbers

**14j** closing the openings of the spaces are disposed on a surface of the flow path substrate **14b** facing the Z2 direction.

The vibration absorber **14j** is a layer formed of an elastic material. The vibration absorbers **14j** form parts of the wall surfaces of the first common liquid chamber R1 and the second common liquid chamber R2 and absorb the pressure variations in the first common liquid chamber R1 and the second common liquid chamber R2.

Each nozzle flow path Nf is a space in a groove formed in a surface of the flow path substrate **14b** facing the Z2 direction. Here, the nozzle substrate **14a** forms a part of the wall surface of the nozzle flow path Nf.

Each of the first communication flow paths Na1 and the second communication flow paths Na2 is a space passing through the flow path substrate **14b**.

Each of the individual supply flow paths Ra1 and the individual discharge flow paths Ra2 is a space passing through the flow path substrate **14b**. Each individual supply flow path Ra1 allows the first common liquid chamber R1 to communicate with the corresponding pressure chamber Ca and supplies ink from the first common liquid chamber R1 to the pressure chamber Ca. Here, one end of the individual supply flow path Ra1 is open on a surface of the flow path substrate **14b** facing the Z1 direction. On the other hand, another end of the individual supply flow path Ra1 is at the upstream end of the individual flow path PJ and is open on the wall surface of the first common liquid chamber R1 in the flow path substrate **14b**. Each individual discharge flow path Ra2 allows the second common liquid chamber R2 to communicate with the corresponding pressure chamber Cb and discharges ink from the pressure chamber Cb to the second common liquid chamber R2. Here, one end of the individual discharge flow path Ra2 is open on a surface of the flow path substrate **14b** facing the Z1 direction. On the other hand, another end of the individual discharge flow path Ra2 is at the downstream end of the individual flow path PJ and is open on the wall surface of the second common liquid chamber R2 in the flow path substrate **14b**.

In the pressure chamber substrate **14c**, the pressure chambers Ca and the pressure chambers Cb of the multiple individual flow paths PJ are formed. Each of the pressure chambers Ca and the pressure chambers Cb passes through the pressure chamber substrate **14c** and is a space between the flow path substrate **14b** and the vibration plate **14d**.

The vibration plate **14d** is a plate-like part that can elastically vibrate. The vibration plate **14d** is, for example, a multilayer structure including a first layer comprised of silicon oxide and a second layer comprised of zirconium oxide. Here, another layer comprised of, for example, metal oxide may be interposed between the first layer and the second layer. A part or the entirety of the vibration plate **14d** may be integrated with and comprised of the same material as the pressure chamber substrate **14c**. For example, the vibration plate **14d** and the pressure chamber substrate **14c** may be formed as a monolithic structure by selectively and partially removing, in the thickness direction, areas corresponding to the pressure chambers C of a plate-like material with a predetermined thickness. Also, the vibration plate **14d** may be comprised of a layer of a single material.

Multiple piezoelectric elements **14e** corresponding to different pressure chambers C are provided on a surface of the vibration plate **14d** facing the Z1 direction. Each piezoelectric element **14e** has, for example, a multilayer structure including a first electrode and a second electrode that face each other and a piezoelectric layer disposed between the first and second electrodes. The piezoelectric element **14e**

changes the pressure of ink in the pressure chamber C and thereby causes the ink in the pressure chamber C to be ejected from the nozzle N. When the drive signal Com is supplied, the piezoelectric element **14e** deforms and thereby causes the vibration plate **14d** to vibrate. This vibration causes the pressure chamber C to expand and contract and as a result, the pressure of ink in the pressure chamber C changes. The piezoelectric element **14e** is an example of a driven element. Here, the liquid ejection head **14** may include heating elements instead of the piezoelectric elements **14e**.

The case **14f** stores ink. The case **14f** forms spaces that constitute remaining parts of the first common liquid chamber R1 and the second common liquid chamber R2 other than the parts formed in the flow path substrate **14b**. Also, the case **14f** includes an inlet IO1 communicating with the first common liquid chamber R1 and an outlet IO2 communicating with the second common liquid chamber R2. Ink is supplied to the first common liquid chamber R1 via the inlet IO1. Also, ink stored in the second common liquid chamber R2 is recovered via the outlet IO2.

The protective plate **14g** is a plate-like part disposed on a surface of the vibration plate **14d** facing the Z1 direction, protects the multiple piezoelectric elements **14e**, and increases the mechanical strength of the vibration plate **14d**. Here, a space for housing the multiple piezoelectric elements **14e** is formed between the protective plate **14g** and the vibration plate **14d**.

The wiring substrate **14h** is mounted on a surface of the vibration plate **14d** facing the Z1 direction and is a component for electrically connecting the controller **90** to the liquid ejection head **14**. The wiring substrate **14h** may be a flexible component such as a flexible printed circuit (FPC) or a flexible flat cable (FFC). A drive circuit **14i** is mounted on the wiring substrate **14h**.

In the liquid ejection head **14** configured as described above, when the circulation mechanism **95** is driven, ink is circulated through the first common liquid chamber R1, the individual supply flow path Ra1, the pressure chamber Ca, the nozzle flow path Nf, the pressure chamber Cb, the individual discharge flow path Ra2, and the second common liquid chamber R2 in this order.

Also, the drive signal Com from the drive circuit **14i** simultaneously drives the piezoelectric elements **14e** corresponding to the pressure chamber Ca and the pressure chamber Cb to change the pressures in the pressure chamber Ca and the pressure chamber Cb. As a result of the changes in the pressures, ink is ejected from the nozzle N.

### 1-3. Filling Process

When filling, with ink, the nozzle N, the individual flow path PJ, the first common liquid chamber R1, the second common liquid chamber R2, the supply flow path SJ, and the recovery flow path CJ that are not filled with ink, the nozzle N, the individual flow path PJ, the first common liquid chamber R1, the second common liquid chamber R2, the supply flow path SJ, and the recovery flow path CJ may be filled with ink by adjusting the pressure in the supply tank **951** to a positive pressure and adjusting the pressure in the recovery tank **952** to a negative pressure as in the circulation operation. However, the pressure loss in the recovery flow path CJ observed when the recovery flow path CJ is not filled with ink is very small compared to the pressure loss observed when the recovery flow path CJ is filled with ink. More precisely, although pressure loss of air occurs, the pressure loss of air is very small compared to the pressure

loss of a liquid. Also, when the recovery flow path CJ is not filled with ink, no pressure acting on the nozzle N is generated by the head difference between the liquid level in the recovery tank 952 and the meniscus in the nozzle N. Accordingly, when a meniscus of ink is formed in the nozzle N but the recovery flow path CJ is not filled with ink, a pressure that is substantially the same as the pressure in the recovery tank 952 acts on the meniscus formed in the nozzle N. When a pressure that differs from the atmospheric pressure by a predetermined amount acts on the meniscus, the meniscus is broken. The pressure at which the meniscus is broken is determined by the surface tension of ink and the perimeter of the hole of the nozzle N. In the descriptions below, the pressure at which the meniscus is broken is referred to as a meniscus breaking pressure. "Pressure" in the descriptions below indicates a pressure relative to the atmospheric pressure unless otherwise mentioned. When a pressure that is relative to the atmospheric pressure and greater than or equal to the meniscus breaking pressure acts on the meniscus and when a pressure that is relative to the atmospheric pressure and less than or equal to the meniscus breaking pressure acts on the meniscus, the meniscus is broken.

When Pm indicates the meniscus breaking pressure, N indicates the surface tension of ink, D indicates the nozzle hole diameter, and π indicates pi, the meniscus breaking pressure Pm is expressed by formula (1) below.

$$Pm=N/(\pi D) \tag{1}$$

In the circulation operation, because the pressure loss occurs in the recovery flow path CJ and formula (2) below is satisfied, ink is circulated without breaking the meniscus.

$$|\text{Pressure acting on meniscus}|<|Pm| \tag{2}$$

Here, |x| means the absolute value of x. Formula (2) can be transformed into formula (2-1) when the pressure acting on the meniscus is a positive pressure and can be transformed into formula (2-2) when the pressure acting on the meniscus is a negative pressure.

$$\text{Pressure acting on meniscus}<|Pm| \tag{2-1}$$

$$\text{Pressure acting on meniscus}>-\text{|Pm|} \tag{2-2}$$

In contrast, in a state where ink has not reached the recovery flow path CJ after the meniscus is formed in the nozzle N, the pressure acting on the meniscus in the nozzle N can be considered to be substantially the same as the pressure Pt\_out in the recovery tank 952. When formula (3) below is satisfied, the meniscus is broken.

$$|Pt\_out|\geq|Pm| \tag{3}$$

When the breaking and the formation of the meniscus are repeated, air bubbles may be drawn into the flow path in the liquid ejection head 14. When the air bubbles enter ink, the supply of ink becomes insufficient or an ejection failure occurs. The ejection failure indicates a state in which even when the drive signal Com is supplied to eject ink from the nozzle N, ink cannot be ejected in a manner defined by the drive signal Com. When ink is ejected from the nozzle N and the pressure in the individual flow path PJ becomes negative, the negative pressure draws ink from the first common liquid chamber R1 and the second common liquid chamber R2. However, the negative pressure not only draws ink from the first common liquid chamber R1 and the second common liquid chamber R2 but also draws the air bubbles remaining in the first common liquid chamber R1 and the second common liquid chamber R2 into the individual flow path PJ, and the air bubbles clog the nozzle N and cause the ejection

failure. To prevent the meniscus from being broken, formula (3) should not be satisfied, that is, formula (4) below denying the formula (3) needs to be satisfied.

$$|Pt\_out|<|Pm| \tag{4}$$

Here, Pt\_out is a negative value. Therefore, formula (5) below is derived from formula (4).

$$0 \text{ [kPa]}>Pt\_out>-\text{|Pm|} \tag{5}$$

Here, [kPa] means kilopascal, which is a unit of pressure. In the first embodiment, in a state in which ink has not reached the recovery flow path CJ after the meniscus of ink is formed in the nozzle N, the controller 90 controls the circulation mechanism 95 such that formula (5) is satisfied. Satisfying formula (5) makes it possible to prevent the already formed meniscus from being broken and thereby makes it possible to prevent the air bubbles from being drawn into the liquid ejection head 14.

1-4. Operation of Controller

FIG. 5 is a flowchart illustrating a process performed by the controller 90 to fill flow paths with ink. As illustrated in FIG. 5, to fill the flow path in the liquid ejection head 14 including the nozzle N, the supply flow path SJ, and the recovery flow path CJ with ink, the controller 90 performs a filling process and the second circulation operation in this order. As the filling process, the controller 90 performs steps S2, S4, S6, S8, S10, S12, S14, and S16 in this order. As illustrated in FIG. 5, the period in which the filling process is performed is referred to as a filling period T1. In the filling period T1, Ta indicates a period from before the meniscus of ink is formed in the nozzle N until the meniscus of ink is formed in the nozzle N. In the filling period T1, Tb indicates a period after the period Ta until ink reaches the recovery flow path CJ after the meniscus of ink is formed in the nozzle N. Also, in the filling period T1, Tc indicates a period that is after the period Tb and in which the first circulation operation is performed after ink reaches the recovery flow path CJ. Here, the period Ta is an example of a "second period". The period Tb is an example of a "first period". The period Tc is an example of a "fourth period".

At step S2, the controller 90 performs a preparation operation as one of the operations in the filling process by controlling the circulation mechanism 95. The preparation operation is described below with reference to FIG. 6.

FIG. 6 is a drawing for describing the preparation operation. In an initial state illustrated in FIG. 6, ink is stored only in the reservoir 93, and ink is not stored in the supply tank 951 and the recovery tank 952. While performing the preparation operation, the controller 90 keeps the on-off valve 9521 and the on-off valve 9511 open. In the preparation operation, the controller 90 controls the pump 94 to send the ink stored in the reservoir 93 to the recovery tank 952. Next, the controller 90 controls the return pump 956 to send the ink from the recovery tank 952 to the supply tank 951. After sending a certain amount of ink to the supply tank 951, the controller 90 ends the preparation operation. Here, at the end of the preparation operation, ink may or may not be stored in the recovery tank 952.

Referring back to FIG. 5, after step S2, the controller 90 performs steps S4, S6, S8, S10, S12, S14, and S16 in this order as the filling process. At step S4, the controller 90 opens the on-off valve 9521 of the recovery tank 952 and closes the on-off valve 9511 of the supply tank 951. Then, at step S6, the controller 90 starts driving the pressurizing mechanism IM and the return pump 956. The time at which

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Pt<sub>in</sub> satisfies formula (a-3) described later after the pressurizing mechanism IM is started to be driven corresponds to the start time of the period Ta. Here, the timing at which the return pump 956 is started to be driven is not limited to step S6. The return pump 956 may be started to be driven before step S16 described later at the latest, and may be started to be driven at, for example, step S12 described later. Next, the state of the liquid ejecting apparatus 100 in the period Ta is described with reference to FIG. 7.

FIG. 7 is a drawing illustrating the state of the liquid ejecting apparatus 100 in the period Ta. In the period Ta, the on-off valve 9521 is open and the on-off valve 9511 is closed. In FIG. 7 and FIGS. 8, 9, and 12 described later, to facilitate the understanding, the on-off valve 9511 in the open state is indicated by an outline figure, and the on-off valve 9511 in the closed state is indicated by a solid figure. The same applies to the on-off valve 9521.

In the period Ta, by satisfying formula (2), the meniscus can be prevented from being broken. The pressure acting on the meniscus is expressed by formula (a-1) below by using the pressure Pt<sub>in</sub> in the supply tank 951, an absolute value ΔPin of pressure loss between the supply tank 951 and the nozzle N, and a pressure Ph<sub>in</sub> that acts on the nozzle N due to the head difference between the liquid level in the supply tank 951 and the nozzle N.

$$\text{Pressure acting on meniscus} = Pt_{in} - \Delta Pin \pm |Ph_{in}| \quad (a-1)$$

Formula (a-1) can be transformed into formula (a-1-1) below when the liquid level in the supply tank 951 is located away from the nozzle N in a direction (Z1 direction) opposite the vertical direction and can be transformed into formula (a-1-2) below when the liquid level in the supply tank 951 is located away from the nozzle N in the vertical direction (Z2 direction).

$$\text{Pressure acting on meniscus} = Pt_{in} - \Delta Pin + |Ph_{in}| \quad (a-1-1)$$

$$\text{Pressure acting on meniscus} = Pt_{in} - \Delta Pin - |Ph_{in}| \quad (a-1-2)$$

Here, when H<sub>in</sub> indicates the distance (head difference) in the vertical direction between the nozzle forming surface FN and the liquid level in the supply tank 951 and g indicates gravitational acceleration, the absolute value of the pressure Ph<sub>in</sub> is expressed by formula (6) below.

$$|Ph_{in}| = H_{in} \times g \quad (6)$$

Also, considering that the ink is caused to flow toward the recovery tank 952, the pressure acting on the meniscus is greater than 0 [kPa]. Formula (a-2) below is obtained by considering the fact that the pressure acting on the meniscus is greater than 0 [kPa] and by substituting the right-hand side of formula (a-1) into the left-hand side of formula (2-1).

$$0 \text{ [kPa]} < Pt_{in} - \Delta Pin \pm |Ph_{in}| < |Pm| \quad (a-2)$$

By applying equivalence transformation to formula (a-2), formula (a-3) below is obtained.

$$(-\Delta Pin \pm |Ph_{in}|) < Pt_{in} < |Pm| - (-\Delta Pin \pm |Ph_{in}|) \quad (a-3)$$

For example, when the liquid level in the supply tank 951 is located away from the nozzle N in the direction (direction Z1) opposite the vertical direction as illustrated in FIG. 7 and when Ph<sub>in</sub> is +1 [kPa], ΔPin is 12 [kPa], and |Pm| is 1 [kPa], formula (a-4) below can be obtained by substituting these values into the corresponding terms in formula (a-3).

$$-(-12 \text{ [kPa]} + 1 \text{ [kPa]}) < Pt_{in} < 1 \text{ [kPa]} - (-12 \text{ [kPa]} + 1 \text{ [kPa]}) \quad (a-4)$$

At step S6, the controller 90 drives the pressurizing mechanism IM and adjusts the pressure set by the regulator

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9515 according to formula (a-4) so that the pressure measured by the pressure sensor 9517 becomes greater than 11 [kPa] and less than 12 [kPa]. Here, in the period Ta, because the on-off valve 9521 is open, Pt<sub>out</sub> is [kPa].

Specific examples of pressures set by the regulator 9515 are described below. When P3 indicates a positive pressure applied by the return pump 956 to the supply tank 951 and P4 indicates a pressure set by the regulator 9515, formula (a-5) below is satisfied.

$$Pt_{in} = P3 + P4 \quad (a-5)$$

Formula (a-6) below is obtained by substituting the right-hand side of formula (a-5) into Pt<sub>in</sub> in formula (a-4) and applying equivalence transformation to the resulting formula.

$$11 \text{ [kPa]} - P3 < P4 < 12 \text{ [kPa]} - P3 \quad (a-6)$$

For example, P3 is from 0.2 [kPa] to 0.5 [kPa] when the return pump 956 is being driven and is 0 [kPa] when the return pump 956 is not being driven. For example, when P3 is 0.2 [kPa], P4 is greater than 10.8 [kPa] and less than 11.8 [kPa] according to formula (a-6). Also, when P3 is 0.5 [kPa], P4 is greater than 10.5 [kPa] and less than 11.5 [kPa] according to formula (a-6).

Referring back to FIG. 5, after step S6, the controller 90 determines, at step S8, whether the meniscus of ink has been formed in the nozzle N. Specifically, the controller 90 determines that the meniscus of ink has been formed in the nozzle N when a first predetermined period has passed after the driving of the pressurizing mechanism IM is started. The first predetermined period is obtained by, for example, adding a margin representing a tolerance to a period obtained by an experiment performed by the manufacturer of the liquid ejecting apparatus 100.

When the determination result of step S8 is negative, the controller 90 performs step S8 again after a predetermined period of time.

When the determination result of step S8 is affirmative, the controller 90, at step S10, closes the on-off valve 9521 of the recovery tank 952. The time at which the determination result of step S8 becomes affirmative corresponds to the end of the period Ta. After step S10, the controller 90, at step S12, starts driving the depressurizing mechanism DM. The time at which Pt<sub>out</sub> satisfies formula (5) after the driving of the depressurizing mechanism DM is started corresponds to the start of the period Tb. The state of the liquid ejecting apparatus 100 in the period Tb is described below with reference to FIG. 8.

FIG. 8 is a drawing illustrating the state of the liquid ejecting apparatus 100 in the period Tb. In the period Tb, because the supply flow path SJ has been filled with ink and the ink has reached the nozzle N, the meniscus of ink is formed in the nozzle N. In FIG. 8, a thick arrow is used for the supply flow path SJ to indicate that the supply flow path SJ has been filled with ink. Also, in FIG. 8, the shading applied to a part of the flow path in the liquid ejection head 14 indicates that the part of the flow path in the liquid ejection head 14 has been filled with ink. Furthermore, in FIG. 8, the shading in the nozzle N indicates that the meniscus of ink has been formed in the nozzle N.

In the period Tb, when formula (5) is satisfied, the meniscus is prevented from being broken. When |Pm| is 1 [kPa], formula (b-1) below is obtained by substituting 1 [kPa] into |Pm| in formula (5).

$$0 \text{ [kPa]} > Pt_{out} > -1 \text{ [kPa]} \quad (b-1)$$

At step S12, the controller 90 drives the depressurizing mechanism DM and adjusts the pressure set by the regulator

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9525 according to formula (b-1) so that the pressure measured by the pressure sensor 9527 falls in a range between 0 [kPa] and -1 [kPa]. Also, in the period Tb, the controller 90 drives and controls the pressurizing mechanism IM in the same manner as in the period Ta.

Specific examples of pressures set by the regulator 9525 are described below. When P1 indicates a negative pressure applied by the return pump 956 to the recovery tank 952 and P2 indicates a pressure set by the regulator 9525, formula (b-2) below is satisfied.

$$P_{t\_out}=P1+P2 \tag{b-2}$$

Formula (b-3) below can be derived by substituting the right-hand side of formula (b-2) into Pt\_out in formula (b-1) and applying equivalence transformation to the resulting formula.

$$-P1>P2>-1 \text{ [kPa]}-P1 \tag{b-3}$$

P1 is, for example, from -0.2 [kPa] to -0.5 [kPa] when the return pump 956 is being driven and is 0 [kPa] when the return pump 956 is not being driven. For example, when P1 is -0.2 [kPa], P2 is less than 0.2 [kPa] and greater than -0.8 [kPa] according to formula (b-3). Also, when P1 is -0.5 [kPa], P2 is less than 0.5 [kPa] and greater than -0.5 [kPa] according to formula (b-3).

Referring back to FIG. 5, after step S12, the controller 90, at step S14, determines whether ink has reached the recovery flow path CJ based on the measurement result of the pressure sensor 954. As described above, the pressure loss in the recovery flow path CJ when the recovery flow path CJ is not filled with ink is very small compared to the pressure loss when the recovery flow path CJ is filled with ink. Therefore, when the number of digits of the pressure measured by the pressure sensor 954 changes greatly, the pressure sensor 954 can detect that ink has reached the recovery flow path CJ. The pressure sensor 953 sends, as measurement information, information indicating whether ink has reached the recovery flow path CJ to the controller 90. When the determination result of step S14 is negative, the controller 90 performs step S14 again after a predetermined period of time.

When the determination result of step S14 is affirmative, the controller 90 performs the first circulation operation at step S16. The time at which the determination result of step S14 becomes affirmative corresponds to the end of the period Tb. In the first circulation operation, the time at which Pt\_in satisfies formula (c-2) described later and Pt\_out satisfies formula (c-5) described later corresponds to the start of the period Tc. The state of the liquid ejecting apparatus 100 in the period Tc is described below with reference to FIG. 9.

FIG. 9 is a drawing illustrating the state of the liquid ejecting apparatus 100 in the period Tc. In the period Tc, the supply flow path SJ and the flow path in the liquid ejection head 14 have been filled with ink, and ink has reached the position where the pressure sensor 954 of the recovery flow path CJ is provided. In FIG. 9, the shading applied to the liquid ejection head 14 indicates that the flow path in the liquid ejection head 14 has been filled with ink. Furthermore, in FIG. 9, a thick line is used for a part of the arrow representing the recovery flow path CJ to indicate that ink has reached the position in the recovery flow path CJ where the pressure sensor 954 is provided.

In the period Tc, to discharge air bubbles, it is necessary to set the differential pressure between Pt\_in and Pt\_out to a sufficiently large value. For example, the controller 90 sets Pt\_in to a value that satisfies formula (c-1) below.

$$|Pm|<Pt\_in-\Delta Pin\pm Ph\_in \tag{c-1}$$

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By applying equivalence transformation to formula (c-1), formula (c-2) below is obtained.

$$P_{t\_in}>|Pm|-(\Delta Pin\pm Ph\_in) \tag{c-2}$$

Formula (c-2) can be transformed into formula (c-2-1) below when the liquid level in the supply tank 951 is located away from the nozzle N in a direction (Z1 direction) opposite the vertical direction and can be transformed into formula (c-2-2) when the liquid level in the supply tank 951 is away from the nozzle N in the vertical direction (Z2 direction).

$$P_{t\_in}>|Pm|-(\Delta Pin+Ph\_in) \tag{c-2-1}$$

$$P_{t\_in}>|Pm|-(\Delta Pin-Ph\_in) \tag{c-2-2}$$

When the liquid level in the supply tank 951 is located away from the nozzle N in the Z1 direction and when Ph\_in is +1 [kPa], ΔPin is 12 [kPa], and |Pm| is 1 [kPa], formula (c-3) below is obtained by substituting these values into the corresponding terms in formula (c-2).

$$P_{t\_in}>1 \text{ [kPa]}-(-12 \text{ [kPa]}+1 \text{ [kPa]})\rightarrow Pt\_in>12 \text{ [kPa]} \tag{c-3}$$

At step S16, the controller 90 drives the pressurizing mechanism IM and adjusts the pressure set by the regulator 9515 according to formula (c-3) so that the pressure measured by the pressure sensor 9517 becomes greater than 12 [kPa].

In relation to the pressure P4 set by the regulator 9515, the positive pressure P3 applied to the supply tank 951 by the return pump 956 is, for example, from 0.2 [kPa] to 0.5 [kPa]. For example, when P3 is 0.2 [kPa], according to formula (a-5) and formula (c-3), P4 is higher than 11.8 [kPa]; and when P3 is 0.5 [kPa], according to formula (a-5) and formula (c-3), P4 is higher than 11.5 [kPa].

For example, the controller 90 sets Pt\_out to a value that satisfies formula (c-4) below.

$$-(\Delta Pout\pm Ph\_out+|Pm|)>Pt\_out \tag{c-4}$$

Here, Ph\_out indicates a pressure that acts on the nozzle N due to the head difference between the liquid level in the recovery tank 952 and the nozzle N. When H\_out indicates the distance (head difference) between the nozzle forming surface FN and the liquid level in the recovery tank 952 in the vertical direction and g indicates gravitational acceleration, the absolute value of the pressure Ph\_out caused by the head difference is represented by formula (7) below.

$$|Ph\_out|=H\_out\times g \tag{7}$$

Formula (c-5) below is obtained by swapping the sides of formula (c-4).

$$Pt\_out<-(\Delta Pout\pm Ph\_out+|Pm|) \tag{c-5}$$

Formula (c-5) can be transformed into formula (c-5-1) below when the liquid level in the recovery tank 952 is located away from the nozzle N in a direction (Z1 direction) opposite the vertical direction and can be transformed into formula (c-5-2) when the liquid level in the recovery tank 952 is located away from the nozzle N in the vertical direction (Z2 direction).

$$Pt\_out<-(\Delta Pout+Ph\_out+|Pm|) \tag{c-5-1}$$

$$Pt\_out<-(\Delta Pout-Ph\_out+|Pm|) \tag{c-5-2}$$

For example, when the liquid level in the recovery tank 952 is located away from the nozzle N in the Z1 direction and when Ph\_out is +1 [kPa], ΔPout is 3 [kPa], and |Pm| is 1 [kPa], formula (c-6) is obtained by substituting these values into the corresponding terms in formula (c-5).

$$P_{t\_out} < -(3 \text{ [kPa]} + 1 \text{ [kPa]} + 1 \text{ [kPa]}) \rightarrow P_{t\_out} < -5 \text{ [kPa]} \quad (c-6)$$

In relation to the pressure P2 set by the regulator **9525**, the negative pressure P1 applied to the recovery tank **952** by the return pump **956** is, for example, from  $-0.2 \text{ [kPa]}$  to  $-0.5 \text{ [kPa]}$ . For example, when P1 is  $-0.2 \text{ [kPa]}$ , according to formula (b-2) and formula (c-6), P2 is lower than  $-4.8 \text{ [kPa]}$ ; and when P1 is  $0.5 \text{ [kPa]}$ , according to formula (b-2) and formula (c-6), P2 is lower than  $-4.5 \text{ [kPa]}$ .

Referring back to FIG. 5, after performing the first circulation operation for the period Tc, the controller **90** performs the second circulation operation at step S18 and ends the process illustrated in FIG. 5. The period Tc is a period that is necessary to sufficiently remove the air bubbles from the flow path in the liquid ejection head **14** by performing the first circulation operation. The period Tc is obtained by, for example, adding a margin representing a tolerance to a period obtained by an experiment performed by the manufacturer of the liquid ejecting apparatus **100**.

The flow rate in the second circulation operation is less than the flow rate in the first circulation operation. For example, the difference between the pressure Pt\_in in the supply tank **951** and the pressure Pt\_out in the recovery tank **952** in the second circulation operation is less than the difference between the pressure Pt\_in in the supply tank **951** and the pressure Pt\_out in the recovery tank **952** in the first circulation operation. Performing the second circulation operation makes it possible to suppress the thickening of ink. When receiving the image data Img during the second circulation operation, the controller **90** performs a print operation.

#### 1-5. Summary of First Embodiment

As described above, the liquid ejecting apparatus **100** according to the first embodiment includes the liquid ejection head **14** including the nozzle N that ejects ink, the supply tank **951** that temporarily stores the ink to be supplied to the liquid ejection head **14**, the recovery tank **952** that temporarily stores the ink recovered from the liquid ejection head **14**, the supply flow path SJ through which the ink is supplied from the supply tank **951** to the liquid ejection head **14**, the recovery flow path CJ through which the ink is recovered from the liquid ejection head **14** to the recovery tank **952**, the pressurizing mechanism IM that pressurizes the inside of the supply tank **951**, and the depressurizing mechanism DM that depressurizes the inside of the recovery tank **952**. In the filling period T1, a filling process is performed to fill, with the ink, the nozzle N, the supply flow path SJ, and the recovery flow path CJ that are not filled with the ink; and the filling period T1 includes the period Tb that is after a meniscus of the ink is formed in the nozzle N until the ink reaches the recovery flow path CJ. The pressurizing mechanism IM and the depressurizing mechanism DM are driven in the period Tb; and formula (5), i.e.,  $P_{t\_out} > -|P_m|$ , is satisfied in the period Tb, where Pm indicates a pressure at which the meniscus of the ink formed in the nozzle N is broken and Pt\_out indicates the pressure in the recovery tank **952**.

In the filling process, the recovery tank **952** is set to a negative pressure to cause the ink to flow from the liquid ejection head **14** toward the recovery tank **652** and thereby fill the recovery flow path CJ with the ink. However, when the recovery tank **952** is set at the negative pressure in the period Tb in the filling process, there is a risk that the meniscus formed in the nozzle N is broken. In the first embodiment, the meniscus is prevented from being broken

due to the negative pressure in the recovery tank **952** by making the absolute value of Pt\_out smaller than the absolute value of Pm, in other words, by setting the negative pressure in the recovery tank **952** to such a value that the meniscus can be prevented from being broken. The liquid ejecting apparatus **100** according to the first embodiment makes it possible to prevent the meniscus from being broken and thereby makes it possible to prevent air bubbles from being drawn into the circulation path KJ during the filling process. As described above, the liquid ejecting apparatus **100** according to the first embodiment can prevent air bubbles from being drawn into the circulation path KJ even when the recovery tank **952** is set to a negative pressure in the filling process.

Also, the filling period T1 includes the period Ta that is before the period Tb and extends from before the meniscus of the ink is formed in the nozzle N until the meniscus of the ink is formed in the nozzle N. In the period Ta, the pressurizing mechanism IM is driven, but the depressurizing mechanism DM is not driven.

When the depressurizing mechanism DM is driven in the period Ta, air is drawn into the nozzle N, and air bubbles become more likely to be drawn into the flow path in the liquid ejection head **14**. For this reason, the liquid ejecting apparatus **100** according to the first embodiment is configured to not drive the depressurizing mechanism DM in the period Ta and can therefore prevent air from being drawn into the circulation path KJ via the nozzle N.

Also, in the period Tc after the period Tb and after the time when the ink reaches the recovery flow path CJ, the controller **90** makes the pressure in the supply tank **951** higher than the pressure in the recovery tank **952** to perform a circulation operation for circulating the ink through the circulation path KJ including the liquid ejection head **14**, the supply tank **951**, the supply flow path SJ, the recovery tank **952**, and the recovery flow path CJ; and formula (c-5), i.e.,  $P_{t\_out} < -(\Delta P_{out} + |P_{h\_out}| + |P_m|)$  is satisfied in the period Tc, where  $\Delta P_{out}$  indicates the absolute value of pressure loss between the recovery tank **952** and the nozzle N and Ph\_out indicates a pressure that acts on the nozzle N due to the head difference between the liquid level in the recovery tank **952** and the nozzle N.

Because pressure loss occurs when the ink reaches the recovery flow path CJ and the pressure Ph\_out is generated due to the head difference when the recovery flow path CJ is filled with the ink, there is a case in which the ink cannot be recovered from the liquid ejection head **14** with the pressure in the recovery tank **952** in the period Tb. For this reason, formula (c-5) is satisfied to make it possible to quickly and reliably send the ink from the liquid ejection head **14** to the recovery tank **952** in the period Tc that is after the time when the ink reaches the recovery flow path CJ.

A part of formula (a-3), specifically,  $P_{t\_in} < |P_m| - (\Delta P_{in} + |P_{h\_in}|)$ , is satisfied in the period Tb, where Pt\_in indicates the pressure in the supply tank **951**,  $\Delta P_{in}$  indicates the absolute value of pressure loss between the supply tank **951** and the nozzle N, and Ph\_in indicates the pressure that acts on the nozzle N due to the head difference between the liquid level in the supply tank **951** and the nozzle N.

By satisfying  $P_{t\_in} < |P_m| - (\Delta P_{in} + |P_{h\_in}|)$ , the liquid ejecting apparatus **100** according to the first embodiment can prevent the ink from leaking out of the nozzle N due to the breaking of the meniscus in the filling process.

Also, in the period Tc, formula (c-2), i.e.,  $P_{t\_in} > |P_m| - (\Delta P_{in} + |P_{h\_in}|)$ , is satisfied.

Satisfying formula (c-2) makes it possible to quickly and reliably send the ink from the liquid ejection head **14** to the

recovery tank **952** in the period  $T_c$  that is after the time when the ink reaches the recovery flow path CJ.

The liquid ejecting apparatus **100** further includes the pressure sensor **954** that detects that the ink has reached the recovery flow path CJ. The liquid ejecting apparatus **100** proceeds from the period  $T_b$  to the period  $T_c$  when the pressure sensor **954** detects that the ink has reached the recovery flow path CJ.

The arrival of the ink at the recovery flow path CJ may also be detected in a manner different from the present embodiment. For example, it is possible to determine, without using the pressure sensor **954**, that the ink has reached the recovery flow path CJ when a second predetermined period has passed after the driving of the pressurizing mechanism IM is started or after the meniscus of the ink is formed in the nozzle N. The second predetermined period may be obtained by, for example, adding a margin representing a tolerance to a period obtained by an experiment performed by the manufacturer of the liquid ejecting apparatus **100**. However, compared to the manner in which it is determined that the ink has reached the recovery flow path CJ when the second predetermined period has passed, the liquid ejecting apparatus **100** according to the first embodiment can quickly proceed to the period  $T_c$  when the ink actually reaches the recovery flow path CJ. Being able to quickly proceed to the period  $T_c$  makes it possible to switch to the first circulation operation at an earlier timing.

The circulation path KJ includes the relay flow path IJ through which the recovery tank **952** communicates with the supply tank **951**, and the return pump **956** is provided in the relay flow path IJ to send the ink from the recovery tank **952** to the supply tank **951**.  $P_2 > -|P_m| - P_1$  is satisfied in the period  $T_b$ , where  $P_1$  indicates a negative pressure generated in the recovery tank **952** by driving the return pump **956** and  $P_2$  indicates a negative pressure generated in the recovery tank **952** by the depressurizing mechanism DM.

In a configuration where the pressurizing mechanism and the depressurizing mechanism are provided separately, the pressure generated by the return pump is normally very small compared to the differential pressure generated during the circulation operation and therefore can be ignored. However, in the period  $T_b$  in the present embodiment, because the negative pressure set in the recovery tank **952** is small, the influence of the pressure generated by the return pump **956** is large. For this reason, in the liquid ejecting apparatus **100** according to the first embodiment, the negative pressure generated in the recovery tank **952** by the depressurizing mechanism DM is set considering the negative pressure generated by driving the return pump **956**. Compared with the manner in which the pressure generated by the return pump **956** is not considered, the configuration of the first embodiment makes it easier to satisfy formula (2) and thereby makes it possible to more effectively prevent the meniscus from being broken.

The above descriptions may also be applied to a liquid filling method in which the liquid ejecting apparatus **100** according to the first embodiment drives the depressurizing mechanism DM such that  $P_{t\_out} > -|P_m|$  is satisfied in the period  $T_b$ , where  $P_m$  indicates a breaking pressure at which the meniscus of the ink formed in the nozzle N is broken and  $P_{t\_out}$  indicates the pressure in the recovery tank **952**.

## 2. Second Embodiment

In the first embodiment, a meniscus of ink is formed in the nozzle N by supplying the ink to the liquid ejection head **14** from the supply tank **951**. However, the method of forming

a meniscus of ink in the nozzle N is not limited to this example. A second embodiment is described below.

FIG. **10** is a drawing illustrating an example of a liquid ejecting apparatus **100-A** according to the second embodiment. The liquid ejecting apparatus **100-A** differs from the liquid ejecting apparatus **100** in that the liquid ejecting apparatus **100-A** includes a wiping mechanism **96** and an application mechanism **97**. The wiping mechanism **96** includes a wiper **961** that contacts the nozzle forming surface FN and is used in an operation for wiping the nozzle forming surface FN.

The wiping mechanism **96** is disposed to face the nozzle forming surface FN when the liquid ejection head **14** is located in a standby position where the nozzle forming surface FN does not face the medium PP. The standby position corresponds to a home position that corresponds to the end point of the back-and-forth movement of the liquid ejection head **14**.

The wiper **961** has a blade shape and is formed of an elastic material such as rubber. The material of the wiper **961** is not limited to an elastic material but may also be a fibrous material such as fabric or nonwoven fabric. The wiper **961** is an example of a "wiping member".

The wiper **961** wipes off substances adhering to the nozzle forming surface FN. Examples of such substances include ink and fragments of the medium PP. The controller **90** wipes off substances adhering to the nozzle forming surface FN by moving either one of the wiper **961** and the nozzle forming surface FN relative to the other. This means that either the liquid ejection head **14** is moved along the X-axis while maintaining the position of the wiper **961** or the wiper **961** is moved along the X-axis while maintaining the position of the liquid ejection head **14**. In the descriptions below, it is assumed that the liquid ejection head **14** is moved along the X-axis while maintaining the position of the wiper **961**.

The application mechanism **97** applies ink to the wiper **961** under the control of the controller **90**. For example, the application mechanism **97** is supplied with ink from the reservoir **93** and applies ink to the wiper **961** while the liquid ejection head **14** is not in the standby position. As illustrated in FIG. **10**, when applying ink, the application mechanism **97** is positioned to overlap the wiper **961** in plan view in the Z-axis direction. To prevent the liquid ejection head **14** from colliding with the application mechanism **97** when the liquid ejection head **14** is in the standby position, the application mechanism **97** may be configured to move in the Z1 direction to such an extent that the collision with the liquid ejection head **14** is prevented or may be configured to move in the X2 direction to such an extent that the collision with the liquid ejection head **14** is prevented. Here, the application mechanism **97** may instead be configured to apply a liquid other than ink to the wiper **961**. The liquid other than ink may be, for example, a cleaning liquid used to improve the wiping performance of wiping the nozzle forming surface FN.

### 2-1. Operation of Controller in Second Embodiment

FIG. **11** is a flowchart illustrating a process performed by the controller **90** to fill flow paths with ink. As illustrated in FIG. **11**, when filling the flow path in the liquid ejection head **14** including the nozzle N, the supply flow path SJ, and the recovery flow path CJ with ink, the controller **90** performs a filling process according to the second embodiment and the second circulation operation in this order. T2 indicates a

filling period in which the filling process according to the second embodiment is performed. In the filling period T2, a period from before a meniscus of ink is formed in the nozzle N until the meniscus of ink is formed in the nozzle N is referred to as a period Td. Also, in the filling period T2, a period that is after the period Td and from after the meniscus of ink is formed in the nozzle N and until the ink reaches the recovery flow path CJ is referred to as a period Tb. The filling period T2 is an example of a “filling period” in the second embodiment. The period Td is an example of a “third period”.

In FIG. 11, the same reference numbers as in FIG. 5 are assigned to steps that are identical to the steps in FIG. 5, and the descriptions of those steps are omitted. As the filling process according to the second embodiment, the controller 90 performs steps S2, S22, S24, S26, S14, and S16 in this order. At step S22, the controller 90 controls the application mechanism 97 to apply ink to the wiper 961 and controls the wiping mechanism 96 to wipe the nozzle forming surface FN with the wiper 961 to which ink is applied and thereby form a meniscus of ink in the nozzle N. As described above, the application mechanism 97 may apply a liquid other than ink to the wiper 961. For example, at step 22, a meniscus of a cleaning liquid may be formed in the nozzle N. The time at which step S22 is started is the start time of the period Td. Also, the time at which step S22 is completed is the end time of the period Td. The state of the liquid ejecting apparatus 100-A immediately after the end of the period Td is described with reference to FIG. 12.

FIG. 12 is a drawing illustrating the state of the liquid ejecting apparatus 100-A immediately after the end of the period Td. Immediately after the end of the period Td, the on-off valve 9511 and the on-off valve 9521 are open. In the period Td, the meniscus of ink is formed in the nozzle N as a result of wiping the nozzle forming surface FN with the wiper 961 to which ink is applied. FIG. 12 illustrates a state in which the nozzle forming surface FN is wiped with the wiper 961 to which ink IK is applied. Also, in FIG. 12, the formation of the meniscus of ink in the nozzle N is indicated by shading in the nozzle N.

Referring back to FIG. 11, after step S22, the controller 90, at step S24, closes the on-off valve 9511 of the supply tank 951 and the on-off valve 9521 of the recovery tank 952. Next, at step S26, the controller 90 starts driving the pressurizing mechanism IM and the depressurizing mechanism DM simultaneously and starts driving the return pump 956. The time at which Pt\_in satisfies formula (a-3) and Pt\_out satisfies formula (5) after the pressurizing mechanism IM and the depressurizing mechanism DM are started to be driven corresponds to the start time of the period Tb. Similarly to the first embodiment, the timing at which the return pump 956 is started to be driven is not limited to step S26. The return pump 956 may be started to be driven before step S16 at the latest. Because Pt\_in and Pt\_out in step S26 are the same as Pt\_in and Pt\_out in the period Tb in the first embodiment, the descriptions of Pt\_in and Pt\_out are omitted here. After step S26, the controller 90 performs step S14.

#### 2-2. Summary of Second Embodiment

As described above, the liquid ejecting apparatus 100-A according to the second embodiment further includes the wiper 961 to which ink is applied, the liquid ejection head 14 includes the nozzle forming surface FN in which the nozzle N is formed, and the filling period T2 includes the period Td that is before the period Tb and in which the

meniscus of ink is formed in the nozzle N by wiping the nozzle forming surface FN with the wiper 961.

The liquid ejecting apparatus 100-A according to the second embodiment does not have to determine the timing at which the period Ta ends, in other words, the liquid ejecting apparatus 100-A according to the second embodiment does not have to determine whether the meniscus of ink has been formed in the nozzle N. Accordingly, the liquid ejecting apparatus 100-A according to the second embodiment does not need to include a mechanism for determining the timing at which the period Ta ends. Therefore, the configuration of the liquid ejecting apparatus 100-A can be simplified compared to the liquid ejecting apparatus 100 according to the first embodiment. Here, generally, the length of the period Td is shorter than the length of the period Ta. Accordingly, compared to the liquid ejecting apparatus 100 according to the first embodiment, the liquid ejecting apparatus 100-A according to the second embodiment can shorten the period from the start of the filling process to the formation of the meniscus of ink in the nozzle N.

Also, in the period Td, the pressurizing mechanism IM and the depressurizing mechanism DM are started to be driven at the same timing.

The liquid ejecting apparatus 100-A according to the second embodiment does not have to determine the timing at which the period Ta ends. Also, the period in which at least one of the pressurizing mechanism IM and the depressurizing mechanism DM is driven corresponds to the period Tb in the second embodiment and corresponds to the period from the start of the period Ta to the end of the period Tb in the first embodiment. The depressurizing mechanism DM is not driven in the period Ta according to the first embodiment. Therefore, it is supposed that the average of the differential pressure between Pt\_in and Pt\_out in the filling period T2 is higher than the average of the differential pressure between Pt\_in and Pt\_out in the filling period T1. For the reasons described above, the average of the flow rate of ink in the filling period T2 is greater than the average of the flow rate of ink in the filling period T1. Therefore, compared to the liquid ejecting apparatus 100 according to the first embodiment, the liquid ejecting apparatus 100-A according to the second embodiment can shorten the filling period T2.

### 3. Variations

Each of the embodiments described above may be modified in various manners. Specific examples of modifications are described below. Two or more variations arbitrarily selected from the examples below may be combined as appropriate unless they do not conflict with each other.

#### 3-1. First Variation

In each of the above embodiments, the pressure sensor 953 is used to detect that ink has reached the recovery flow path CJ. However, any other means may also be used to detect that ink has reached the recovery flow path CJ.

FIG. 13 is a drawing for describing a liquid ejecting apparatus 100-B according to a first variation. The liquid ejecting apparatus 100-B differs from the liquid ejecting apparatus 100 in that the liquid ejecting apparatus 100-B includes an optical sensor 993 including a light emitter 991 and a light receiver 992 instead of the pressure sensor 953 and includes a recovery flow path CJ-B instead of the recovery flow path CJ. FIG. 13 illustrates a cross-section of

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a part of the recovery flow path CJ-B and a portion around the part of the recovery flow path CJ-B. In the first variation, the optical sensor **993** is an example of a “detector”.

The light emitter **991** is capable of emitting light under the control of the controller **90**. The light receiver **992** receives the light emitted by the light emitter **991**. In the descriptions below, for brevity, the light emitted by the light emitter **991** may be referred to as “emitted light”. The emitted light may be any type of light, such as ultraviolet light, visible light, or infrared light, that can be detected by the light receiver **992**. A part TR of the recovery flow path CJ-B is formed of a material that is translucent to the emitted light. The material of the part TR may be, for example, a transparent resin material. Alternatively, the entire recovery flow path CJ-B may be formed of a material that is translucent to the emitted light. Ink according to the first variation is not cured by the emitted light. Also, it is assumed that the ink according to the first variation has a property of blocking the emitted light.

As illustrated in FIG. **13**, the part TR is provided between the light emitter **991** and the light receiver **992**. When the ink has not reached the part TR, light emitted from the light emitter **991** passes through the part TR and reaches the light receiver **992**. In contrast, when the ink has reached the part TR, the light emitted from the light emitter **991** is blocked by the ink and does not reach the light receiver **992**. Therefore, the optical sensor **993** can detect whether the ink is in the part TR based on the result of detecting the emitted light by the light receiver **992**. Thus, the optical sensor **993** is a so-called transmissive optical sensor. The ink in the part TR does not have to completely block the emitted light. As long as the ink in the part TR attenuates the light emitted from the light emitter **991**, even if the attenuated light reaches the light receiver **992**, the light receiver **992** can determine whether the ink is present in the part TR by detecting whether the light from the light emitter **991** has been attenuated.

As described above, the liquid ejecting apparatus **100-B** according to the first variation further includes the optical sensor **993** including the light emitter **991** configured to emit light and the light receiver **992** configured to receive the light emitted from the light emitter **991**. The part TR of the recovery flow path CJ-B is formed of a material that is translucent to the light emitted from the light emitter **991**, and the optical sensor **993** is configured to detect whether the ink is present in the part TR.

There is a type of ink, such as UV ink, that cures when exposed to light. Here, UV stands for ultra violet. However, general ink does not have a property of curing when exposed to light. Therefore, the liquid ejecting apparatus **100-B** according to the first variation can easily detect that ink has reached the recovery flow path CJ-B regardless of the type of ink used, unless the ink has a property of being cured by the light emitted by the light emitter **991**.

In the first variation, it is assumed that the ink has a property of blocking the emitted light. However, the ink may be translucent to the emitted light. Even when ink is translucent to the emitted light, the refractive index of ink is normally different from the refractive index of air. Therefore, the positional relationship among the light emitter **991**, the light receiver **992**, and the part TR may be set such that the light emitted from the light emitter **991** when the ink is not present in the part TR reaches the light receiver **992** and the light emitted from the light emitter **991** when the ink is present in the part TR is refracted in the ink and does not reach the light receiver **992**.

### 3-2. Second Variation

In the first variation, the optical sensor **993** is a transmissive optical sensor and configured such that the part TR is

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provided between the light emitter **991** and the light receiver **992**. However, the configuration of the optical sensor **993** is not limited to this example. For example, in plan view in a direction orthogonal to a straight line extending along the part TR, the light emitter **991** and the light receiver **992** may be provided in a space on one side of a central axis corresponding to the straight line extending along the part TR, and a reflecting plate for reflecting the emitted light may be provided in a space on the other side of the central axis. When the ink has not reached the part TR, the light emitted from the light emitter **991** is reflected by the reflecting plate and reaches the light receiver **992**. In contrast, when the ink has reached the part TR, the light emitted from the light emitter **991** is blocked by the ink in the part TR and does not reach the light receiver **992**.

### 3-3. Third Variation

In the first embodiment and the second embodiment, the pressure sensor **954** is an example of a “detector”; and in the first variation and the second variation, the optical sensor **993** is an example of a “detector”. However, the “detector” is not limited to the pressure sensor **954** and the optical sensor **993**. For example, a flowmeter provided in the recovery flow path CJ may be used as the “detector”. The flowmeter may be, for example, an ultrasonic flowmeter, an electromagnetic flowmeter, or a thermal flowmeter.

### 3-4. Fourth Variation

In each of the above embodiments, the reservoir **93** is configured to supply ink to the recovery tank **952**. However, the configuration of the reservoir **93** is not limited to this example. For example, the reservoir **93** may be configured to supply ink to the supply tank **951**. In a preparation operation according to the fourth variation, the controller **90** sends ink stored in the reservoir **93** to the supply tank **951**. Next, after closing the on-off valve **9511** of the supply tank **951**, the controller **90** sends ink in the supply tank **951** to the recovery tank **952** by reversing the return pump **956**. Here, sending the ink in the supply tank **951** to the recovery tank **952** is not necessarily performed.

### 3-5. Fifth Variation

In the fourth variation, the ink in the supply tank **951** is sent to the recovery tank **952** by reversing the return pump **956** after closing the on-off valve **9511** of the supply tank **951**. However, the ink in the supply tank **951** may be sent to the recovery tank **952** in a manner different from the fourth variation. For example, the controller **90** may be configured to close the on-off valve **9521** of the recovery tank **952** after sending the ink stored in the reservoir **93** to the supply tank **951** and then set the pressure in the recovery tank **952** to a negative pressure by using the depressurizing mechanism DM. By setting the pressure in the recovery tank **952** to a negative pressure, the liquid ejecting apparatus **100** can send the ink in the supply tank **951** to the recovery tank **952**.

### 3-6. Sixth Variation

In the first embodiment and in each variation based on the first embodiment, the controller **90** determines that a meniscus of ink has been formed in the nozzle N when the first predetermined period has passed after starting to drive the pressurizing mechanism IM. However, the formation of the meniscus of ink may also be determined in any other

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appropriate manner. For example, the formation of the meniscus of ink in the nozzle N may be determined based on a measurement result of the pressure sensor 954. When a state in which the meniscus of ink has not been formed in the nozzle N and the recovery flow path CJ is in communication with the atmosphere via the nozzle N changes to a state in which the meniscus of ink has been formed in the nozzle N and the recovery flow path CJ is not in communication with the atmosphere, the pressure measured by the pressure sensor 954 changes greatly. Accordingly, the pressure sensor 954 can detect that the meniscus of ink has been formed in the nozzle N. The pressure sensor 954 sends, to the controller information indicating that the meniscus of ink has not been formed in the nozzle N, information indicating that the meniscus of ink has been formed in the nozzle N, and information indicating that the ink has reached the recovery flow path CJ as measurement information.

The liquid ejecting apparatus 100 according to the sixth variation can quickly proceed to the period  $T_b$  after the meniscus of ink is actually formed in the nozzle N. Being able to quickly proceed to the period  $T_b$  makes it possible to shorten the filling period  $T_1$ .

## 3-7. Seventh Variation

In each of the above embodiments, the liquid ejecting apparatus 100 includes the pressure sensor 954 that detects that ink has reached the recovery flow path CJ. However, the configuration of the liquid ejecting apparatus 100 is not limited to this example. For example, the liquid ejecting apparatus 100 does not necessarily include the pressure sensor 954. In this case, the liquid ejecting apparatus 100 may determine that ink has reached the recovery flow path CJ when the second predetermined period has passed after the pressurizing mechanism IM is started to be driven or after the meniscus of ink is formed in the nozzle N. Because the liquid ejecting apparatus 100 according to the seventh variation does not need to include the pressure sensor 954, the configuration of the liquid ejecting apparatus 100 according to the seventh variation can be simplified compared to the liquid ejecting apparatus 100 according to the first embodiment.

## 3-8. Eighth Variation

In each of the above embodiments, it is assumed that the liquid ejecting apparatus 100 is a serial printer in which the housing case 921 is moved back and forth in the X-axis direction. However, the present disclosure is not limited to this example. For example, the liquid ejecting apparatus 100 may be implemented as a line printer in which multiple nozzles N are distributed across the entire width of the medium PP.

## 3-9. Ninth Variation

Each of the liquid ejecting apparatuses according to the above embodiments may be used for a device dedicated for printing and may also be used for other types of devices such as a facsimile machine and a copier. Also, the use of the liquid ejecting apparatuses according to the present disclosure is not limited to printing. For example, a liquid ejecting apparatus configured to eject a solution of a color material may be used as a manufacturing device for forming a color filter of a liquid crystal display device. Also, a liquid ejecting apparatus configured to eject a solution of a conductive

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material may be used as a manufacturing device for forming wiring and electrodes of a wiring substrate.

## 4. Appendices

Configurations as described below may be derived from the above embodiments.

A liquid ejecting apparatus according to a first aspect of the present disclosure includes a liquid ejection head including a nozzle that ejects a liquid, a supply tank that temporarily stores the liquid to be supplied to the liquid ejection head, a recovery tank that temporarily stores the liquid recovered from the liquid ejection head, a supply flow path through which the liquid is supplied from the supply tank to the liquid ejection head, a recovery flow path through which the liquid is recovered from the liquid ejection head to the recovery tank, a pressurizing mechanism that pressurizes the inside of the supply tank, and a depressurizing mechanism that depressurizes the inside of the recovery tank. A filling period, in which a filling process is performed to fill, with the liquid, the nozzle, the supply flow path, and the recovery flow path that are not filled with the liquid, includes a first period that is after a meniscus of the liquid is formed in the nozzle and before the liquid reaches the recovery flow path. In the first period, the pressurizing mechanism and the depressurizing mechanism are driven; and in the first period,  $P_{t\_out} > -|P_m|$  is satisfied, where  $P_m$  indicates a pressure at which the meniscus of the liquid formed in the nozzle is broken and  $P_{t\_out}$  indicates a pressure in the recovery tank.

According to the first aspect, the absolute value of  $P_{t\_out}$  is made smaller than the absolute value of  $P_m$ . This makes it possible to prevent the meniscus from being broken due to the negative pressure in the recovery tank. According to the first aspect, the meniscus is prevented from being broken. This in turn makes it possible to prevent air bubbles from being drawn into the circulation path during the filling process.

According to a second aspect that is a specific example of the first aspect, the filling period includes a second period that is before the first period and is from before the meniscus of the liquid is formed in the nozzle until the meniscus of the liquid is formed in the nozzle; and in the second period, the pressurizing mechanism is driven, and the depressurizing mechanism is not driven.

When the depressurizing mechanism is driven in the second period, air is drawn into the nozzle, and air bubbles become more likely to be drawn into the flow path in the liquid ejection head. Accordingly, by not driving the depressurizing mechanism DM, the second aspect can prevent air from being drawn into the circulation path through the nozzle.

According to a third aspect that is a specific example of the first aspect, the liquid ejecting apparatus further includes a wiping member to which the liquid is applied, the liquid ejection head includes a nozzle forming surface in which the nozzle is formed, and the filling period includes a third period that is before the first period and in which the meniscus of the liquid is formed in the nozzle by wiping the nozzle forming surface with the wiping member.

The liquid ejecting apparatus according to the third aspect does not have to determine the timing at which the second period ends. Therefore, the third aspect eliminates the need to provide a mechanism for determining the timing at which the second period ends and thereby makes it possible to simplify the configuration of the liquid ejecting apparatus compared to the second aspect.

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According to a fourth aspect that is a specific example of the third aspect, in the first period, the pressurizing mechanism and the depressurizing mechanism are started to be driven at the same timing.

At least one of the pressurizing mechanism and the depressurizing mechanism is driven in the first period according to the fourth aspect and is driven in a period from the start of the second period to the end of the first period according to the second aspect. In the second period according to the second aspect, the depressurizing mechanism is not driven. Therefore, it is supposed that the average of the differential pressure between  $P_{t\_in}$  and  $P_{t\_out}$  in the filling period according to the fourth aspect is higher than the average of the differential pressure between  $P_{t\_in}$  and  $P_{t\_out}$  in the filling period according to the second aspect. Accordingly, the fourth aspect makes it possible to shorten the filling period compared to the second aspect.

According to a fifth aspect that is a specific example of the first aspect, the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path; in the fourth period, a circulation operation is performed to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; and in the fourth period,  $P_{t\_out} < -(\Delta P_{out} \pm |P_{h\_out}| + |P_m|)$  is satisfied, where  $\Delta P_{out}$  indicates the absolute value of pressure loss between the recovery tank and the nozzle and  $P_{h\_out}$  indicates a pressure acting on the nozzle due to a head difference between a liquid level in the recovery tank and the nozzle.

Because pressure loss occurs when the liquid reaches the recovery flow path CJ and the pressure  $P_{h\_out}$  is generated due to the head difference when the recovery flow path is filled with the liquid, there is a case in which the liquid cannot be recovered from the liquid ejection head with the pressure in the recovery tank in the first period. For this reason,  $P_{t\_out} < -(\Delta P_{out} \pm |P_{h\_out}| + |P_m|)$  is satisfied to make it possible to quickly and reliably send the liquid from the liquid ejection head to the recovery tank in the fourth period that is after the liquid reaches the recovery flow path.

According to a sixth aspect that is a specific example of the first aspect, in the first period,  $P_{t\_in} < |P_m| - (-\Delta P_{in} \pm |P_{h\_in}|)$  is satisfied, where  $P_{t\_in}$  indicates a pressure in the supply tank,  $\Delta P_{in}$  indicates the absolute value of pressure loss between the supply tank and the nozzle, and  $P_{h\_in}$  indicates a pressure acting on the nozzle due to a head difference between a liquid level in the supply tank and the nozzle.

By satisfying  $P_{t\_in} < |P_m| - (-\Delta P_{in} \pm |P_{h\_in}|)$ , the sixth aspect makes it possible to prevent the liquid from leaking out of the nozzle due to the breaking of the meniscus during the filling process.

According to a seventh aspect that is a specific example of the sixth aspect, the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path; in the fourth period, a circulation operation is performed to make the pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; and in the fourth period,  $P_{t\_in} > |P_m| - (-\Delta P_{in} \pm |P_{h\_in}|)$  is satisfied.

Satisfying  $P_{t\_in} > |P_m| - (-\Delta P_{in} \pm |P_{h\_in}|)$  makes it possible to quickly and reliably send the liquid from the liquid ejection head to the recovery tank in the fourth period that is after the liquid reaches the recovery flow path.

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In an eighth aspect that is a specific example of the first aspect, the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path; in the fourth period, a circulation operation is performed to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; the liquid ejecting apparatus further includes a detector that detects that the liquid has reached the recovery flow path; and the liquid ejecting apparatus proceeds from the first period to the fourth period when the detector detects that the liquid has reached the recovery flow path.

According to the eighth aspect, the liquid ejecting apparatus can quickly proceed to the fourth period when the liquid actually reaches the recovery flow path.

According to a ninth aspect that is a specific example of the eighth aspect, the detector is an optical sensor including a light emitter configured to emit light and a light receiver configured to receive the light emitted from the light emitter; at least a part of the recovery flow path is formed of a material that is translucent to the light emitted from the light emitter; and the optical sensor is configured to detect whether the liquid is present in the part.

The ninth aspect makes it possible to easily detect that the liquid has reached the recovery flow path regardless of the type of liquid used, unless the liquid has a property of being cured by the light emitted by the light emitter.

According to a tenth aspect that is a specific example of the first aspect, the liquid ejecting apparatus is configured to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; the circulation path also includes a relay flow path through which the recovery tank communicates with the supply tank; a return pump is provided in the relay flow path to send the liquid from the recovery tank to the supply tank; and in the first period,  $P_2 > -|P_m| - P_1$  is satisfied, where  $P_1$  indicates a negative pressure generated in the recovery tank by driving the return pump and  $P_2$  indicates a negative pressure generated in the recovery tank by the depressurizing mechanism.

In the first period, because the negative pressure set in the recovery tank is small, the influence of the pressure generated by the return pump is large. For this reason, according to the tenth aspect, the negative pressure generated in the recovery tank by the depressurizing mechanism is set considering the negative pressure generated by driving the return pump. Compared with the manner in which the pressure generated by the return pump is not considered, the tenth aspect makes it easier to satisfy  $P_{t\_out} > -|P_m|$  and thereby makes it possible to more effectively prevent the meniscus from being broken.

An eleventh aspect of the present disclosure provides a liquid filling method performed by a liquid ejecting apparatus that includes a liquid ejection head including a nozzle that ejects a liquid, a supply tank that temporarily stores the liquid to be supplied to the liquid ejection head, a recovery tank that temporarily stores the liquid recovered from the liquid ejection head, a supply flow path through which the liquid is supplied from the supply tank to the liquid ejection head, a recovery flow path through which the liquid is recovered from the liquid ejection head to the recovery tank, a pressurizing mechanism that pressurizes the inside of the supply tank, and a depressurizing mechanism that depres-

surizes the inside of the recovery tank. The liquid filling method includes when a filling period, in which a filling process is performed to fill, with the liquid, the nozzle, the supply flow path, and the recovery flow path that are not filled with the liquid, includes a first period that is after a meniscus of the liquid is formed in the nozzle and before the liquid reaches the recovery flow path, driving the depressurizing mechanism such that  $P_{t\_out} > -|P_m|$  is satisfied in the first period, where  $P_m$  indicates a pressure at which the meniscus of the liquid formed in the nozzle is broken and  $P_{t\_out}$  indicates a pressure in the recovery tank.

The eleventh aspect provides effects similar to those provided by the first aspect.

According to a twelfth aspect that is a specific example of the eleventh aspect, the filling period includes a second period that is before the first period and is from before the meniscus of the liquid is formed in the nozzle until the meniscus of the liquid is formed in the nozzle; and in the second period, the pressurizing mechanism is driven but the depressurizing mechanism is not driven.

The twelfth aspect provides effects similar to those provided by the second aspect.

According to a thirteenth aspect that is a specific example of the eleventh aspect, the liquid ejecting apparatus further includes a wiping member to which the liquid is applied, the liquid ejection head includes a nozzle forming surface in which the nozzle is formed, and the filling period includes a third period that is before the first period and in which the meniscus of the liquid is formed in the nozzle by wiping the nozzle forming surface with the wiping member.

The thirteenth aspect provides effects similar to those provided by the third aspect.

According to a fourteenth aspect that is a specific example of the eleventh aspect, in the first period, the pressurizing mechanism and the depressurizing mechanism are started to be driven at the same timing.

The fourteenth aspect provides effects similar to those provided by the fourth aspect.

According to a fifteenth aspect that is a specific example of the eleventh aspect, the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path; in the fourth period, a circulation operation is performed to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; and in the fourth period,  $P_{t\_out} < -(\Delta P_{out} \pm |P_{h\_out}| + |P_m|)$  is satisfied, where  $\Delta P_{out}$  indicates the absolute value of pressure loss between the recovery tank and the nozzle and  $P_{h\_out}$  indicates a pressure acting on the nozzle due to a head difference between a liquid level in the recovery tank and the nozzle.

The fifteenth aspect provides effects similar to those provided by the fifth aspect.

According to a sixteenth aspect that is a specific example of the eleventh aspect, in the first period,  $P_{t\_in} < |P_m| - (-\Delta P_{in} \pm |P_{h\_in}|)$  is satisfied, where  $P_{t\_in}$  indicates a pressure in the supply tank,  $\Delta P_{in}$  indicates the absolute value of pressure loss between the supply tank and the nozzle, and  $P_{h\_in}$  indicates a pressure acting on the nozzle due to a head difference between a liquid level in the supply tank and the nozzle.

The sixteenth aspect provides effects similar to those provided by the sixth aspect.

According to a seventeenth aspect that is a specific example of the sixteenth aspect, the filling period includes a

fourth period that is after the first period and after the liquid reaches the recovery flow path; in the fourth period, a circulation operation is performed to make the pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; and in the fourth period,  $P_{t\_in} > |P_m| - (-\Delta P_{in} \pm |P_{h\_in}|)$  is satisfied.

The seventeenth aspect provides effects similar to those provided by the seventh aspect.

According to an eighteenth aspect that is a specific example of the eleventh aspect, the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path; in the fourth period, a circulation operation is performed to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; the liquid ejecting apparatus further includes a detector that detects that the liquid has reached the recovery flow path; and the filling process proceeds from the first period to the fourth period when the detector detects that the liquid has reached the recovery flow path.

The eighteenth aspect provides effects similar to those provided by the eighth aspect.

According to a nineteenth aspect that is a specific example of the eighteenth aspect, the detector is an optical sensor including a light emitter configured to emit light and a light receiver configured to receive the light emitted from the light emitter; at least a part of the recovery flow path is formed of a material that is translucent to the light emitted from the light emitter; and the optical sensor is configured to detect whether the liquid is present in the part.

The nineteenth aspect provides effects similar to those provided by the ninth aspect.

According to a twentieth aspect that is a specific example of the eleventh aspect, a pressure in the supply tank is made higher than the pressure in the recovery tank and the liquid is thereby circulated through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; the circulation path also includes a relay flow path through which the recovery tank communicates with the supply tank; a return pump is provided in the relay flow path to send the liquid from the recovery tank to the supply tank; and in the first period,  $P_2 > -|P_m| - P_1$  is satisfied, where  $P_1$  indicates a negative pressure generated in the recovery tank by driving the return pump and  $P_2$  indicates a negative pressure generated in the recovery tank by the depressurizing mechanism.

The twentieth aspect provides effects similar to those provided by the tenth aspect.

What is claimed is:

1. A liquid ejecting apparatus comprising:
  - a liquid ejection head including a nozzle configured to eject a liquid;
  - a supply tank temporarily storing the liquid to be supplied to the liquid ejection head;
  - a recovery tank temporarily storing the liquid recovered from the liquid ejection head;
  - a supply flow path supplying the liquid from the supply tank to the liquid ejection head;
  - a recovery flow path recovering the liquid from the liquid ejection head to the recovery tank;

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- a pressurizing mechanism pressurizing an inside of the supply tank; and
- a depressurizing mechanism depressurizing an inside of the recovery tank, wherein
- a filling period, in which a filling process is performed to fill, with the liquid, the nozzle, the supply flow path, and the recovery flow path that are not filled with the liquid, includes a first period that is after a meniscus of the liquid is formed in the nozzle and before the liquid reaches the recovery flow path;
- in the first period, the pressurizing mechanism and the depressurizing mechanism are driven; and
- in the first period,  $P_{t\_out} > -|P_m|$  is satisfied, where  $P_m$  indicates a pressure at which the meniscus of the liquid formed in the nozzle is broken and  $P_{t\_out}$  indicates a pressure in the recovery tank.
2. The liquid ejecting apparatus according to claim 1, wherein
- the filling period includes a second period that is before the first period and is from before the meniscus of the liquid is formed in the nozzle until the meniscus of the liquid is formed in the nozzle; and
- in the second period, the pressurizing mechanism is driven and the depressurizing mechanism is not driven.
3. The liquid ejecting apparatus according to claim 1, further comprising:
- a wiping member to which the liquid is applied, wherein the liquid ejection head includes a nozzle forming surface in which the nozzle is formed; and
- the filling period includes a third period that is before the first period and in which the meniscus of the liquid is formed in the nozzle by wiping the nozzle forming surface with the wiping member.
4. The liquid ejecting apparatus according to claim 3, wherein
- in the first period, the pressurizing mechanism and the depressurizing mechanism are started to be driven at a same timing.
5. The liquid ejecting apparatus according to claim 1, wherein
- the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path;
- in the fourth period, a circulation operation is performed to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; and
- in the fourth period,  $P_{t\_out} < -(\Delta P_{out} \pm |P_h_{out}| + |P_m|)$  is satisfied, where  $\Delta P_{out}$  indicates an absolute value of pressure loss between the recovery tank and the nozzle and  $P_h_{out}$  indicates a pressure acting on the nozzle due to a head difference between a liquid level in the recovery tank and the nozzle.
6. The liquid ejecting apparatus according to claim 1, wherein
- in the first period,  $P_{t\_in} < |P_m| - (-\Delta P_{in} \pm |P_h_{in}|)$  is satisfied, where  $P_{t\_in}$  indicates a pressure in the supply tank,  $\Delta P_{in}$  indicates an absolute value of pressure loss between the supply tank and the nozzle, and  $P_h_{in}$  indicates a pressure acting on the nozzle due to a head difference between a liquid level in the supply tank and the nozzle.
7. The liquid ejecting apparatus according to claim 6, wherein

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- the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path;
- in the fourth period, a circulation operation is performed to make the pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; and
- in the fourth period,  $P_{t\_in} > |P_m| - (-\Delta P_{in} \pm |P_h_{in}|)$  is satisfied.
8. The liquid ejecting apparatus according to claim 1, wherein
- the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path;
- in the fourth period, a circulation operation is performed to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path;
- the liquid ejecting apparatus further comprises a detector configured to detect that the liquid reached the recovery flow path; and
- the liquid ejecting apparatus proceeds from the first period to the fourth period based on the detector detects that the liquid reached the recovery flow path.
9. The liquid ejecting apparatus according to claim 8, wherein
- the detector is an optical sensor including a light emitter configured to emit light and a light receiver configured to receive the light emitted from the light emitter;
- at least a part of the recovery flow path is formed of a material that is translucent to the light emitted from the light emitter; and
- the optical sensor is configured to detect whether the liquid is present in the part.
10. The liquid ejecting apparatus according to claim 1, wherein
- the liquid ejecting apparatus is configured to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path;
- the circulation path also includes a relay flow path through which the recovery tank communicates with the supply tank;
- a return pump is provided in the relay flow path to send the liquid from the recovery tank to the supply tank; and
- in the first period,  $P_2 > -|P_m| - P_1$  is satisfied, where  $P_1$  indicates a negative pressure generated in the recovery tank by driving the return pump and  $P_2$  indicates a negative pressure generated in the recovery tank by the depressurizing mechanism.
11. A liquid filling method performed by a liquid ejecting apparatus that includes
- a liquid ejection head including a nozzle configured to eject a liquid,
- a supply tank temporarily storing the liquid to be supplied to the liquid ejection head,
- a recovery tank temporarily storing the liquid recovered from the liquid ejection head,
- a supply flow path supplying the liquid from the supply tank to the liquid ejection head,

a recovery flow path recovering the liquid from the liquid ejection head to the recovery tank,  
 a pressurizing mechanism pressurizing an inside of the supply tank, and  
 a depressurizing mechanism depressurizing an inside of the recovery tank,  
 the liquid filling method comprising:  
 when a filling period, in which a filling process is performed to fill, with the liquid, the nozzle, the supply flow path, and the recovery flow path that are not filled with the liquid, includes a first period that is after a meniscus of the liquid is formed in the nozzle and before the liquid reaches the recovery flow path, driving the depressurizing mechanism such that  $P_{t\_out} > -|P_{m}|$  is satisfied in the first period, where  $P_m$  indicates a pressure at which the meniscus of the liquid formed in the nozzle is broken and  $P_{t\_out}$  indicates a pressure in the recovery tank.

12. The liquid filling method according to claim 11, wherein  
 the filling period includes a second period that is before the first period and is from before the meniscus of the liquid is formed in the nozzle until the meniscus of the liquid is formed in the nozzle; and  
 in the second period, the pressurizing mechanism is driven and the depressurizing mechanism is not driven.

13. The liquid filling method according to claim 11, wherein  
 the liquid ejecting apparatus further includes a wiping member to which the liquid is applied;  
 the liquid ejection head includes a nozzle forming surface in which the nozzle is formed; and  
 the filling period includes a third period that is before the first period and in which the meniscus of the liquid is formed in the nozzle by wiping the nozzle forming surface with the wiping member.

14. The liquid filling method according to claim 13, wherein  
 in the first period, the pressurizing mechanism and the depressurizing mechanism are started to be driven at a same timing.

15. The liquid filling method according to claim 11, wherein  
 the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path;  
 in the fourth period, a circulation operation is performed to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; and  
 in the fourth period,  $P_{t\_out} < -(\Delta P_{out} \pm |P_{h\_out}| + |P_{m}|)$  is satisfied, where  $\Delta P_{out}$  indicates an absolute value of pressure loss between the recovery tank and the nozzle and  $P_{h\_out}$  indicates a pressure acting on the nozzle due to a head difference between a liquid level in the recovery tank and the nozzle.

16. The liquid filling method according to claim 11, wherein  
 in the first period,  $P_{t\_in} < |P_{m}| - (-\Delta P_{in} \pm |P_{h\_in}|)$  is satisfied, where  $P_{t\_in}$  indicates a pressure in the supply tank,  $\Delta P_{in}$  indicates an absolute value of pressure loss

between the supply tank and the nozzle, and  $P_{h\_in}$  indicates a pressure acting on the nozzle due to a head difference between a liquid level in the supply tank and the nozzle.

17. The liquid filling method according to claim 16, wherein  
 the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path;  
 in the fourth period, a circulation operation is performed to make the pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path; and  
 in the fourth period,  $P_{t\_in} > |P_{m}| - (-\Delta P_{in} \pm |P_{h\_in}|)$  is satisfied.

18. The liquid filling method according to claim 11, wherein  
 the filling period includes a fourth period that is after the first period and after the liquid reaches the recovery flow path;  
 in the fourth period, a circulation operation is performed to make a pressure in the supply tank higher than the pressure in the recovery tank and thereby circulate the liquid through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path;  
 the liquid ejecting apparatus further includes a detector configured to detect that the liquid reached the recovery flow path; and  
 the filling process proceeds from the first period to the fourth period when the detector detects based on that the liquid reached the recovery flow path.

19. The liquid filling method according to claim 18, wherein  
 the detector is an optical sensor including a light emitter configured to emit light and a light receiver configured to receive the light emitted from the light emitter;  
 at least a part of the recovery flow path is formed of a material that is translucent to the light emitted from the light emitter; and  
 the optical sensor is configured to detect whether the liquid is present in the part.

20. The liquid filling method according to claim 11, wherein  
 a pressure in the supply tank is made higher than the pressure in the recovery tank and the liquid is thereby circulated through a circulation path including the liquid ejection head, the supply tank, the supply flow path, the recovery tank, and the recovery flow path;  
 the circulation path also includes a relay flow path through which the recovery tank communicates with the supply tank;  
 a return pump is provided in the relay flow path to send the liquid from the recovery tank to the supply tank; and  
 in the first period,  $P_2 > -|P_{m}| - P_1$  is satisfied, where  $P_1$  indicates a negative pressure generated in the recovery tank by driving the return pump and  $P_2$  indicates a negative pressure generated in the recovery tank by the depressurizing mechanism.